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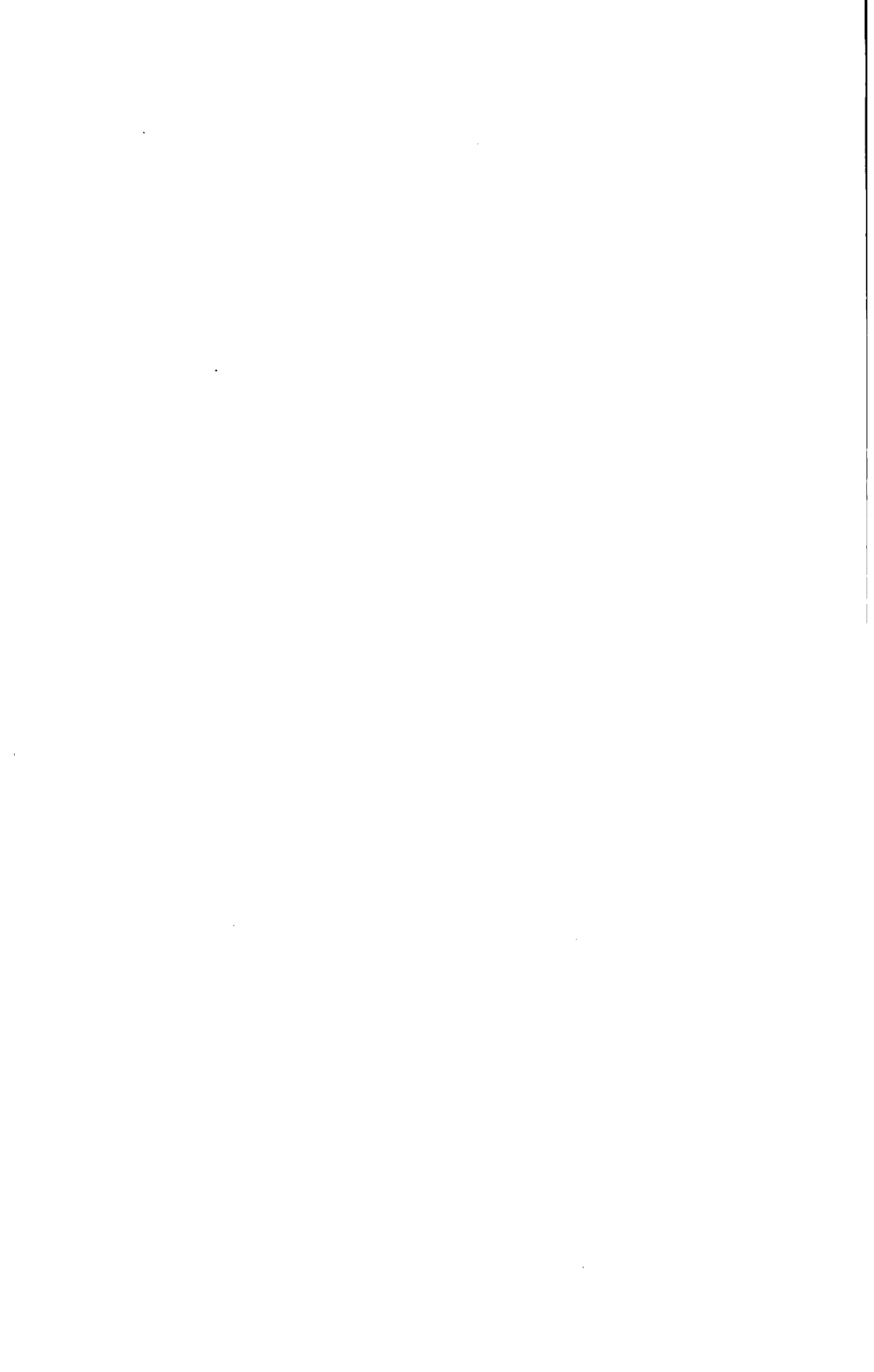


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**Bulletin of the Museum of Comparative Zoölogy**  
**AT HARVARD COLLEGE.**

**VOL. LVI. No. 1.**

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**GEOLOGICAL SERIES, Vol. I. SHALER MEMORIAL SERIES, No. 1.**

**GEOLOGICAL EXPEDITION TO BRAZIL AND CHILE,**  
**1908-1909.**

**By J. B. WOODWORTH.**

**WITH THIRTY-SEVEN PLATES.**

**CAMBRIDGE, MASS., U. S. A.:**  
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No. 1.— *Geological Expedition to Brazil and Chile, 1908–1909.*

By J. B. WOODWORTH.

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I. PREFATORY NOTE TO THE SHALER MEMORIAL  
SERIES.

THE late Dean Shaler, at first Professor of Palaeontology and later Professor of Geology at Harvard University, during his long career as naturalist and teacher, both by his writings and his teaching, displayed a very wide interest in the various aspects of the earth's sciences. When in commemoration of his long services to the University a group of over seven hundred of its alumni raised an endowment of more than \$30,000. for the purpose of maintaining and publishing the results of investigations suitable to his memory, the Division of Geology, to which this gift was entrusted, found itself provided with a fund for the advancement of knowledge in the entire field of its scope.

The following are the terms governing the use of the Shaler Memorial Fund (see the letter of gift in the Annual Report of the Curator of the Museum of Comparative Zoölogy for 1906–07, Cambridge, 1908, p. 19–20).

“The researches here contemplated are to be undertaken by persons nominated by the Committee of the Division of Geology and appointed by the Corporation, whether officers or students of Harvard University or not. The subject and the locality or field of research are to be approved by the

Division Committee, preference being given to studies of an advanced and original character. The sums of money allotted from the income for research are to be determined by the Division Committee with the approval of the Corporation. The money appropriated for such work from the income of the fund shall be in addition to the salary that would be otherwise paid to the person or persons undertaking it; and any work or journey thus supported in whole or in part shall be carried on under the name "Shaler Memorial Research" or "Shaler Memorial Expedition."

"The publications here contemplated are to include the results of original research carried on with the income of the fund, or independently of such aid; but the results must in all cases receive the approval of the Division Committee as to subject and presentation — though not necessarily as to the conclusions stated — before they are accepted for publication.

"All publications thus approved, whether appearing in independent volumes or in some established journal, shall bear the general title, "Shaler Memorial Series." The allotment of money for publication shall be determined in the same way as for research.

"Beneficiaries under the fund, either as to research or publication, may be invited by the Division Committee to give one or more public lectures in Cambridge on the results of their studies, under the general title "Shaler Memorial Lectures," but no additional payment is to be made for these lectures.

"The income of the fund may be allowed to accumulate in case an investigation, expedition, or publication of considerable magnitude is contemplated by the Division Committee, but it is not desired that such accumulation shall continue beyond a reasonable period of time."

In geology, the action of volcanoes, the phenomena of the contact of sea and land, and the evidences of past glaciation particularly occupied Professor Shaler's thoughts. This last subject was a direct inheritance from his master Louis Agassiz. With James Croll, Professor Shaler went further than Louis Agassiz did in perceiving evidences of glacial periods in the geological record long anterior to the great ice-age whose recognition was the lasting contribution of Louis Agassiz to geological science. Professor Shaler anticipated the discovery in the conglomeratic formations of the closing Palaeozoic era of signs of glaciers, which only in recent years have been thoroughly scrutinized by others and found to be veritable products of glacial action. With a view to contributing to the advancement of knowledge in this field, the Division of Geology voted that a grant of money from the Shaler Memorial Fund be expended by the author for the exploration of the Permian conglomerates of the region south of São Paulo in Brazil, the glacial origin of which had already been advanced by Dr.

Orville A. Derby. The report herewith submitted is the result of that expedition. After the rainy season had begun in Brazil, I devoted the time at my disposal to a brief examination of the changes of level on the coast of southern Chile.

Other investigations will be undertaken from time to time as the state of the fund may warrant expenditures.

## II. INTRODUCTION.

In presenting the itinerary of portions of the region traversed, I have taken the most convenient way of recording numerous observations not pertinent to the main object of the journey. Some of the phenomena dealt with in this report have long been described in other languages but without much discussion of causes or of geological correlation. On this account I have been led into a free exercise of the geologist's privilege, if not his proper task,—to interpret his observations and in the language of Robert Hooke “to raise a chronology out of them.” The chapter on the Triassic trap plateau presents the results of a rapid reconnaissance of a little known geological field quite unfamiliar to North American students, and the account of the topographic relief of south Brazil is a sketch *en route* embodying observations in a more systematic order than as if left to discrete and unrelated paragraphs in an account of scientific travel.

Through the courtesy of Dr. Orville A. Derby, the recently appointed Director of the Mineralogical and Geological Service of Brazil it was arranged to conduct the Shaler Memorial party to the glacial boulder-beds of Paraná. To further facilitate the work of the expedition Dr. Euzebio Paulo de Oliveira, Assistant geologist of the Service, was detailed by the Director to act as “interpreter, guide, and friend.” We were met by Dr. Oliveira on the confines of Paraná where I found him engaged in making a geological map of the state. The generous conduct of this young geologist in placing freely at my disposition the results of his observations upon the distribution of the strata and in allowing me to examine his collections of rocks and fossils makes me much indebted to him for many of the facts presented in this report. With him and his pack-train I made the expedition across the trap plateau from Rio Negro to Lages and later he made with me the excursion up the valley of the Rio Tubarão in Santa Catharina. Throughout these journeys the transportation was supplied by the Brazilian Survey. Without this financial assistance the work could not have been carried so far, and without the guidance

afforded by Dr. Derby and his coadjutor many of the best localities would not have been found in the short time that was at my disposal.

Dr. João Cardoso, the Director of the Geological and Geographical Commission of São Paulo kindly detailed Dr. Pacheco, Geologist of that survey to accompany me on the trip from Itaicý to Piracicaba in that state and to Dr. Pacheco's acquaintance with that region I owe much.

In Chile, as a delegate of Harvard University to the Pan-American Congress held in December, 1908, I was accorded free transportation on the government railways through the courtesy of the Director of railways, a privilege which I exercised in the journey from Concepcion to Valdivia and return to Santiago and thence eventually to Valparaíso. Special rates were also given in the passage on the Chilean steamer *Limari* from Valparaíso to Panama; both of these favors reduced the expenses of the Shaler Memorial Expedition.

Prof. Robert DeC. Ward of Harvard University was appointed a member of the Expedition to carry on studies in climatology and to gather material for a course on the geography of South America. He accompanied me as far as Ponta Grossa in Paraná, whence he journeyed to Paranaguá, going by steamer to Santos, thence by rail to São Paulo, and so to Rio de Janeiro, from which port he took ship for New York in August, 1908. The more important publications resulting from his investigations are listed on p. 137.

Mr. Winthrop P. Haynes, an undergraduate student in the University, was appointed Assistant in geology and accompanied me at his own expense as far as Ponta Grossa and Paranaguá, whence he also returned to the United States in August, 1908. He aided in the collection of rocks and fossils in northern Paraná.

I have retained the Portuguese spelling of the Brazilian names used in the text. The pronunciation of these is similar to the Spanish but the following peculiarities should be noted:—*Ch* is regularly and *x* ordinarily equivalent to *sh* in English; *g* soft before *e* and *i* is like the French *j*. Words ending in *am* and *ão* have Portuguese nasal sounds in which the nasal *a* is pronounced somewhat as *ou* in *out* with the lips slightly closed at the end as if to give the letter *m*. Likewise names ending in *im* are nasalized like *ing* in English but with the final *m* sound slightly given.

## III. ITINERARY.

"The usual bane of such expeditions is hurry; because men seldom allot themselves half the time they should do: but, fixing on a day for their return, post from place to place, rather as if they were on a journey that required dispatch, than as philosophers investigating the works of nature."

GILBERT WHITE. *The Natural History of Selborne*. Letter XXVI, December 8, 1769. London: 1789, p. 73.

The first Shaler Memorial Expedition following a generation after the Thayer Expedition to Brazil sailed from New York for Rio de Janeiro on the 20th of June, 1908, on the Steamship *Voltaire* of the Lamport and Holt Line. As previously stated the party consisted of Professor Ward, Mr. W. P. Haynes, and the author in charge. The ship touched at Bahia on July 5th, and reached Rio de Janeiro on the 8th of that month.

On this lonesome tract straight out from the North American coast at New York to Cape St. Roque the voyageur sights few vessels. The minor changes of a June and enjoyable sea, the endless piles of trade clouds, a solar annual eclipse — that of June 28th, — the first view of the Southern Cross, the doldrums and their rains, the so-called "green ray" of the setting sun, — these were the events of the voyage of the *Voltaire* for those members of the party who made their first crossing of the equatorial line.

At Rio de Janeiro we were met and taken care of by Dr. Orville A. Derby, Director of the Mineralogical and Geological Service of Brazil, and under his tutelage began preparations for the journey to the planalto of south Brazil. Our stay in the Capitol was somewhat lengthened by the necessity of awaiting the discharge of Mr. Haynes from the English Hospital, to which institution he had been obliged to go for the treatment of an infected bruise received on shipboard. At this time and indeed through my stay in Brazil, the Capitol suffered greatly from an epidemic of small-pox. According to reports given out on leaving the country as many as 6,722 deaths were caused by this disease in Rio de Janeiro between January 1st and November 22nd, 1908.

During this interval I visited Petropolis from which point under the guidance of Dr. Miquel Arrojado Ribeiro Lisboa an excursion was made to the valley of the Piabanha and the picturesque Valle do Retiro (see Plate 1), a characteristic portion of the eroded coastal

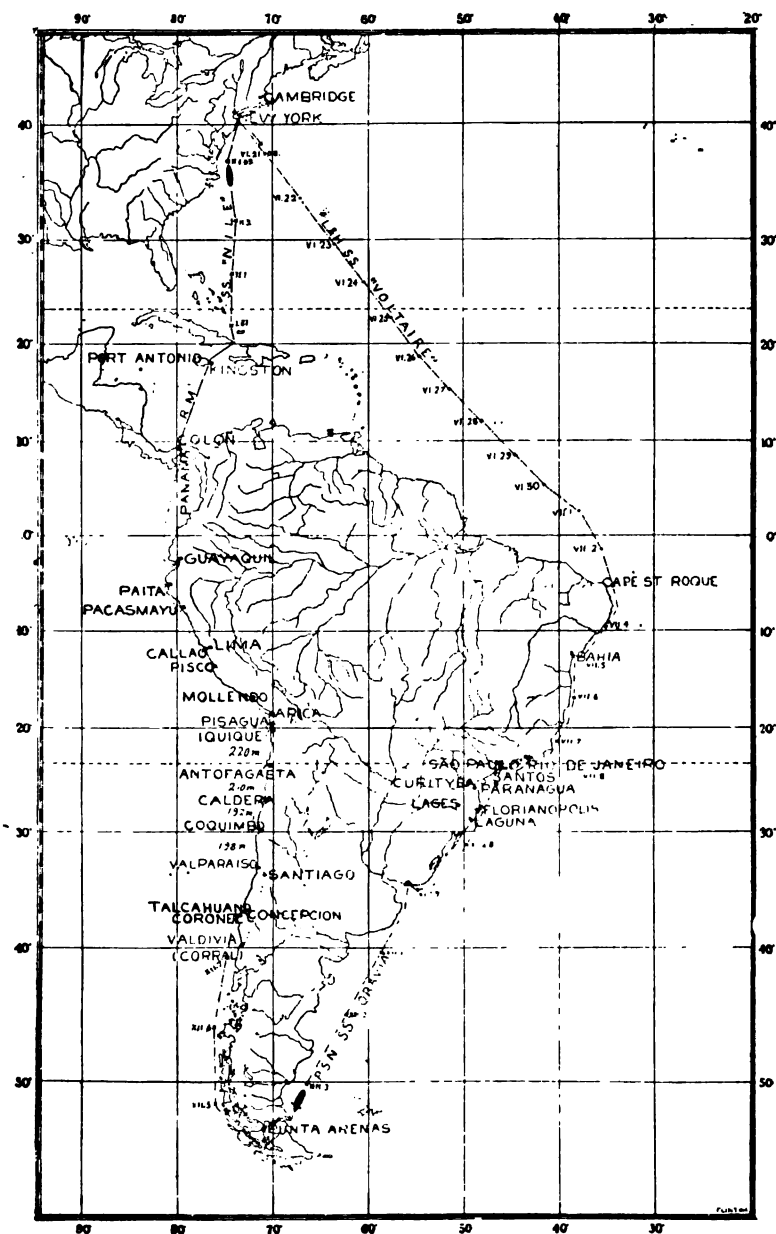


FIG. 1.—Route map of the Expedition from New York to South America and return.

border of the Brazilian tableland constituting the so-called Serra do Mar.

Many maps of Brazil published in that country bear lines of longitude reckoned from the position of the National Observatory in Rio de Janeiro, which lies in  $43^{\circ} 10' 21.15''$  West Long. from Greenwich. The only high-grade maps, outside of certain municipal contoured maps, have been published by the Comissão Geologica e Geographica de São Paulo. Old-fashioned hachured maps of the topography exist for some states but they are all inadequate for the purpose of geological mapping. The territory of Brazil is vast and the interior so little developed that it cannot be expected that the general government can undertake, at present, the making of such maps of its domain as exist for several of the European states, or even a map of the serviceable character of the topographic map of the United States of America. In the case of the state of Paraná I was not able to procure in published form, even an approximately accurate map though a very useful manuscript map is in existence to which I had access. The small-scale map of Santa Catharina published by the State is fairly good for exploratory work. The best general map of São Paulo is that of Williams.

Of the geological text-books which circulate mostly in Brazil, owing to the higher education being based largely on the system of the French, there are several editions of the elementary hand-book of the late Professor de Lapparent. A Portuguese translation by Dr. B. F. Ramiz Galvão, of the third edition of the elementary text, entitled *Resumo de Geologia*, with appendices relating to the geology of Brazil by Dr. Derby, is much used in the schools where geology is taught. Prof. John C. Branner published in 1906 an elementary geological text written in Portuguese with special reference to Brazilian students and embellished with illustrations from native sources including cuts of South American fossils.

The National Exposition at Rio de Janeiro in 1908, held to commemorate the centenary of the opening of the ports of the country, resulted in the bringing together of a collection of rocks and minerals from many parts of this vast territory. Most of these exhibits were intended to set forth the economic resources of the several states. The best of these state collections was that from São Paulo formerly under the directorship of Dr. Derby. From the new territory of Alto Acre there was a small collection of rocks including a dark pebbly sandstone locally used for whetstones, ferruginous sandstone, and a fragment of an ironstone concretion, incorrectly labelled as an aerolite!

gypsum, and samples of clay. From Piauhý there were bottled sulphurous mineral waters, talc, kaolin, graphite, concretionary hematite, and fossil wood. From Sergipe, crystalline limestone and a compact, light-colored argillite used for construction. From Ceará, porphyritic granite, a red granite coarsely crystalline, fossil cetacean bones from Cruxatú, copper carbonate from Milágres, concretions with fossil fishes, and tile work. Alagoas sent pottery products, particularly water-jars made from the clay of Penedo on the Rio Francisco, noted for their porosity and consequent evaporating capacity and cooling power, the most preferred carafes in Brazil. The exhibit also included granites and marbles, among the latter a dark and light-banded crystalline crumpled variety; garnets and black tourmalines. From Rio Grande do Norte, there were soapstone, beryl, and aquamarines; Cretaceous and Tertiary limestones; yellow bricks, salt from the evaporating pans of Caico and Macau, and gypsum from Carambas. Rio Grande do Sul exhibited bituminous coal from the Permian; agates from the Triassic trap sheets; wolframite from Rio Pardo; cuprite, indigolite from Bagé; molybdenite, covellina, native copper from Colonia militar; tin ore; besides artificial stone-ware and colored tiles. From the state of Pará, the exhibits consisted chiefly of clay products, such as bricks and drain-pipes from Cametá and Belem. From Matto Grosso there were gold and diamonds from Coxipo mirim; diamonds and sapphire gravel from the Rio Coxim; gold and diamonds from a basal conglomerate beneath a Devonian sandstone; besides ores of manganese, hematite, and exhibits of limestones. The state of Amazonas was represented by gneisses and schists, silicified wood, artificial stone-ware, tiles and bricks manufactured from Tertiary clays. Goyaz furnished muscovite in merchantable plates, gold, galena, amethyst, rutile, diamonds, yellow quartz (now exported), rose quartz, limonite, soapstones, and millstones. Maranhão had an exhibit of gold. Bahia supplied a collection of minerals, including manganese from Napareth, muscovite from Conquista (said to exist in commercial quantities), monazite sands from Prado, tabatinga (ochreous clays of a variety of colors), copper carbonate from Bom Fim, manganese, limestone, a fine compact brownish limestone with a tendency to a shelly fracture and often horizontally banded from Campo Formoso; granites and gneisses, including a red gneissoid granite from Jacaricy, talc blocks from Caruanyba, lithographic (*sic*) limestone from Carinhanha and Bom Jardim; clay products, including red porous water-jars. The state of Santa Catharina furnished exhibits of the Permian coal, manganese

from Itajahy, molybdenite from Morro do Bahú, magnetite, ochres, slates, and the products of a newly established cement industry. Minas Geraes (the state of "general mines") exhibited of ordinary minerals manganese, itabarite from the well-known peak, micaceous hematite, limonite ores, and clay products from Bello Horizonte; but the most striking exhibit was made by the Morro Velho Mine which, in addition to a rich display of ore, put on exhibition a model showing the working of the ore shutes, the shafts, and levels, with a suitable explanation, in itself the most complete exhibit in the collection.

The newly established federal survey exhibited a relief map of the vicinity of Rio de Janeiro and an excellent series of enlarged photographs illustrative of types of Brazilian rocks and landscapes.

There is a great abundance of manganese in Brazil and from reliable reports received then and since it is most probable that Brazil is destined to be a producer of iron on a large scale and owing to the belated resort to these deposits will enjoy prosperity from this resource when the workable ores of the United States have been exhausted.

Our party left Rio de Janeiro on *July 22nd*, for São Paulo. The points of geological interest on the line of the railway include Mt. Tingua among the lower peaks of the Serra do Mar, which furnished the dikes of phonolite consisting of an alkali feldspar, nepheline, and aegirine to which rock Rosenbusch (Hunter and Rosenbusch, 1890) gave the name *tinguaite*. A good view of the black mountain may be obtained from Ottoni Station. On passing the crest of the Serra and attaining the valley of the Parahyba the Serra da Mantiqueira comes into view, culminating in Mt. Itatiaia, a mass of nepheline-augite syenite or phonolite, the loftiest point in Brazil, 2,994 meters (9,493 ft.), and the highest in South America outside of the Andes. Its summit is a bare rock with weathered out joint-structure forming needles on a large scale. It is plainly seen from Rezende Station. H. H. Smith (1879, p. 441) states that snow occasionally covers the summit.

The Tertiary deposits in the valley of the Parahyba are followed for many leagues by the railway. In the dry season the train in traversing these plains stirs up a fine reddish dust which penetrates the closest cars.

Near Pindamonhangaba Station I noticed two or three broad shallow lakelets in the weathered surface of the rock, a type of basin which abounds in the old weathered surface of Brazilian rocks.

At Taubaté Station an oil shale is distilled from the Tertiary beds, and Dr. Derby states that peat deposits occur near this place.

*July 23rd.*— The day was spent in São Paulo. At the office of the Geological and Geographical Commission of the state there is to be seen a unique collection of fossil silicified wood from the Permian northwest of the city and some skeletons of *Stereosternum*, a reptile occurring in the upper Permian. Among the sections of a diamond drill recently obtained from a boring in the Permian strata I detected a glaciated pebble with well-defined striae in a blue tillite bed, a discovery which at once promised much for the objects of the expedition. An excursion was made to the vicinity of the American College for the purpose of studying the *terra roxa* which in the state of São Paulo plays so large a role in the cultivation of the coffee plant.

*July 24th.*— We left São Paulo at an early hour by the Sorocabana railroad for the end of the line at Bury. At São Roque the line enters a valley with outcrops of slates and limestones, an apparently infolded member of the Pre-Devonian terrane of which the gneisses and schists of the Serra do Mar region are the most ancient parts. The railway follows along the contact of the limestone with granite as far as Mayrink Station, beyond which town the slate belt is followed. Beyond Pantoja Station a blue limestone crops out and kilns have been built for making lime. Slates and limestones continue along the route to Rodovahlo Station, where there is a cement factory. From Pyragibu to Sorocaba the road leaves the belt of metamorphosed sediments, and passes over granites and gneisses. The disintegration of the porphyritic granite, as pointed out by Dr. Derby, produces the granitic surface sands known as *sumarão*, while weathering of a deeper sort changes the granites and gneisses to a clay which from its habit of balling under the shoe is called *massa pé*.

From Sorocaba onward to Bury the route lay over the Permian area of sandstones, shales, and intercalated tillite beds. The line passes within sight of the Ypanema stock some three miles in diameter forming a slight elevation above the general level and mainly composed of eruptive rocks in the Pre-Permian terrane. The igneous mass is a nepheline syenite with segregations of magnetite famous for its early use as an iron ore. Ferreira says the ore was discovered in 1578. At Ypanema there are quarries in a grey sandstone of the Permian, and old iron furnaces, perhaps the site of the earliest production of iron in America.

Throughout the day the mainly open unwooded campos of the upland, or planalto as the Brazilians term the slightly accidented

surface of the plateau, was the striking feature in the landscape. Long round swells or hills with graceful curves to the stream ways betokened everywhere the long continued action of erosion. The excellent topographic maps of this portion of the state by Mr. Horatio Williams begun by the Geological and Geographical Commission of São Paulo under the directorship of Dr. Derby made it possible to follow the route intelligently and interpret the general outlines of the erosive history of the district. In a following chapter on the geomorphology of the region, I have made free use of these maps.

*July 25th.*— In 1908, the passenger service of the railway terminated at Bury, but a line in process of construction extended the communication by rail to Ponta Grossa in Paraná, and so into connection with points on the south far towards the boundary of Uruguay. As will be shown in the sequel the fresh cuttings of the rocks and surface deposits along this new line afforded an exceptional opportunity to study the geology not only of the underlying Permian tillite beds but also of the superficial gravels and their cover of red earths variously known as *terra roxa*, etc. This day we proceeded on a flat car some 18 kilometers along the line of construction, completing the journey to Faxina by a sort of carriage known as a "trolley." While traversing the high campos a hailstorm came up from the west with a well-defined horizontal vortical ring of black clouds, from which hail associated with rain fell so as to coat the ground with hailstones. For nearly an hour after the passage of the storm the small streams now in flood carried a thick load of hailstones. This fall of hail within the subtropical region at an elevation of 900 meters above the sea suggested an inquiry as to the occurrence of hail at lower elevations nearer the equator as a possible factor in the Permian glaciation since it appears that in this way ice may be precipitated in regions where snow never falls.

*July 26th.*— Being unable to secure a conveyance to Itararé, the day was spent in Faxina. This town is underlain by the Devonian sandstone, a light colored to whitish rock, with cross-bedded layers, and occasional bands of white quartz pebbles. Nodules of clay occur also embedded in the sandstone. The strata are well exposed in a ravine on the outskirts of the town.

*July 27th.*— Having procured the means for the conveyance of our party to São Pedro de Itararé on the boundary of Paraná, we journeyed to that place. For most of the day the route lay over the Permian basal sandstones which appeared in the stream bottoms, sometimes with thin beds of white quartz pebbles but without trace of compound

conglomerates such as constitute the tillite beds. Some of the coarse gritty beds contained clay particles. In all probability these were once grains of feldspar indicating that the unaltered rock was a granitic sandstone related to arkose. Dikes or sills of basic intrusives occasionally intersect the sandstone along this route.

*July 28th.*—Through the courtesy of Dr. Cruz Lima we travelled in a special car from Itararé to Jaguariahyva, stopping in the newly opened railway cuts to examine the tillite beds. At the first stop in a cut above the Rio Jaguaricatu in Paraná a well-striated pebble was found in a boulder-bed, establishing at once the identity of origin of these deposits with those of India and South Africa.

*July 29th.*—Continued the journey by rail to Ponta Grossa, the headquarters of the party engaged in the geological survey of Paraná.

The railway from Jaguariahyva to Ponta Grossa crosses the Devonian sandstone cuesta affording a magnificent view of the country.

Between Pirahy and Coxambú the Pre-Devonian rocks, exposed in a lowland widened out along the course of the Rio Yapo, comprise a tilted group of rocks of which I have seen no account in the descriptions of the metamorphosed district of the Serra do Mar. At Pirahy Station there is a monoclinel set of beds in a ridge west of the railroad. The beds strike north by east and dip about 30° west. About a mile south of Pirahy at a water-tank a felsitic breccia crops out. Farther south the train passes through a cut in which slightly metamorphosed shales, sandstones, and a pebble bed with fragments of red felsite, granite, etc., appear, having a reddish color and dipping westward at an angle of about 30 degrees. These rocks from their relatively unmetamorphosed condition appear to be younger than the belt of slates and limestones described as occurring in São Paulo. No fossils were seen in the section nor did time permit a satisfactory search for further details of the stratigraphy. This formation, so different from the members of the Pre-Devonian terrane on the east, is the most western member of the highly inclined rocks seen in Paraná and suggests that some horizon between the Middle Devonian and the slate and limestone terrane may yet be worked out and correlated in this field.

Several days were spent at Ponta Grossa in the examination of the surrounding country, including a visit to Conchas where a bed of tillite is to be seen. In the Carboniferous sandstones west of Ponta Grossa I found some worm burrows of the type known as Monocraterion; these show a cup-shaped superior termination and a vertical

tube penetrating to the bottom of the layer, some five inches in thickness. The tubes were filled with a fine greenish shale. (Fig. {2.}) Similar burrows occur in Pennsylvania in the Ordovician (J. P. Lesley, '89, 1, p. 417-418) but seemingly are of no diagnostic value in determining the age of the strata in which they occur. It is possible that the cup at the orifice of the tube in *Monocraterion* is due to the caving in of the sands prior to their covering by the superincumbent layer, and that thus it is not to be taken as showing the form of the anterior portion of the animal which made the burrow.

From Ponta Grossa an excursion was made under the guidance of Dr. Derby to Curitiba and thence to the coast at Paranaguá. An excellent view of the profile of the plateau and the Serra do Mar was obtained and I have utilized the data in what follows on the geomorphology of south Brazil. From Ponta Grossa also I set out for a trip via Rio Negro, over the trap plateau to Lages in Santa Catharina. As the itinerary of this expedition includes some observations upon the general character of the country not embodied in North American geographical writings, I have transcribed this portion of my Journal with but slight condensation.

*A Journey from Rio Negro to Lages and return to Porto da União on the Iguassú.* It having been decided to make a reconnaissance of the section from Serrinha on the upper waters of the Iguassú to Rio Negro and thence southwards to the base of the Triassic escarpment, the traverse was continued southwards to Lages. The Triassic formation was examined for any evidence which might have a bearing on the transition period following that of Permian glaciation. Dr. Euzebio Paulo de Oliveira and myself set out from Ponta Grossa on August 13 by rail for Rio Negro, the end of the railway, making stops at Tamanduá, Serrinha, and Lapa. A synopsis of my notes on the geology of this portion of the route is embodied in ensuing chapters on the Permian deposits. See Plate 19 for map of route.

At Rio Negro we heard of the Bugres, wild aborigines who infest the trap escarpment on the south and often ambush lonely travellers on the pass over the Serra do Espigão. Southwest of this high point along the Serra Geral there is a remnant, so I was informed, of the

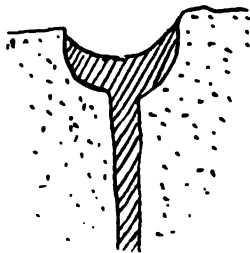


FIG. 2.— *Monocraterion* sp.  
A worm burrow occurring in Permian sandstones on the banks of Lagoado grande near Ponta Grossa, Paraná.

Botocudos, whose haunts are carefully avoided by Brazilian travellers. These naked savages sometimes commit outrages on the new Euro-

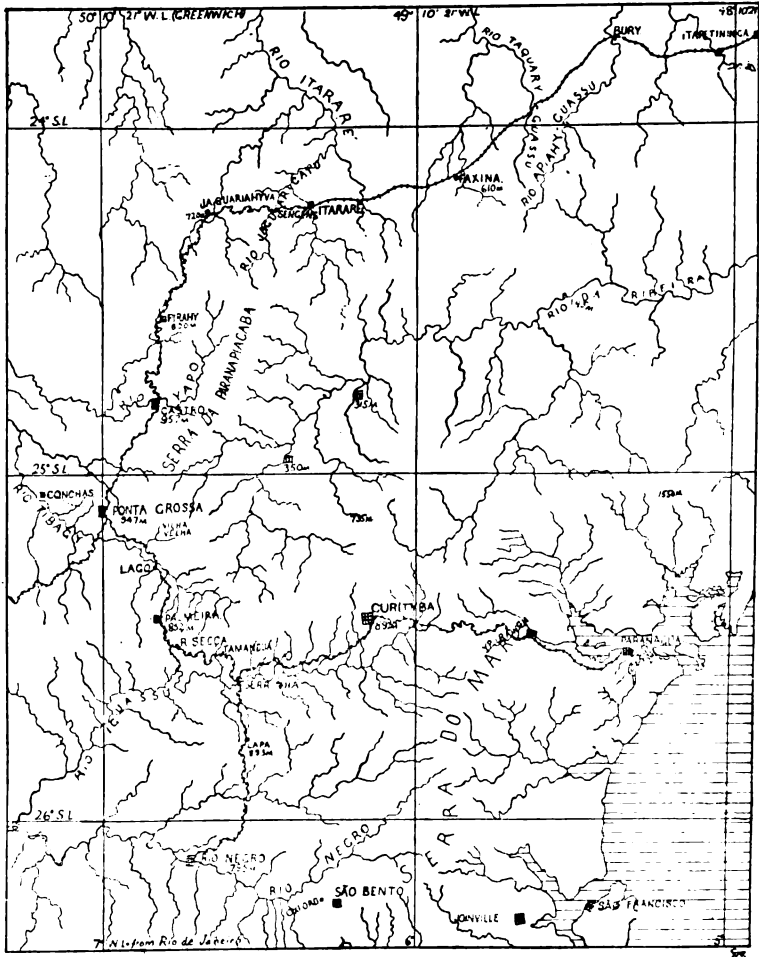


FIG. 3.—Sketch map of eastern Paraná showing localities visited by J. B. Woodworth.

pean settlers who have colonized the lands back from the old occupied sites of the coast. It seems strange to the visitor from North America to find here within a hundred miles of the Atlantic coast conditions

of European settlement such as characterised the period of the first third of the 18th century in the New England states and New York. The topography of this portion of Brazil, its inaccessibility, and the inutility to the older inhabitants of European origin of a large stretch of country along the ragged escarpment of the trap plateau accounts in large part for this lingering of a hostile primitive people in close proximity to the coast; encouraged and abetted by a more or less easy communication for the untrammelled native by larger bodies of indigenous folk in the hinterland of Paraná, where, among the Coroadas savage life remains in yet greater exemption from the restraining influences of advancing civilization. The extension of the railway from Porta da União southward across the trap plateau divides these people and promises to bring to an end a frontier struggle which has endured too long.

Our pack-train having arrived at Rio Negro, we prepared for the expedition to Lages. The equipment for geological field work in this region is extremely simple. For the four members of our force, one light tent was provided, poles for which were cut from night to night in the forest surrounding our camp sites. The baggage was carried in wicker baskets or panniers lashed on pack-saddles. Our provisions consisted of prepared black beans, boiled rice, farinha meal, broad thin slabs of drier beef known as xarque, and a supply of powdered burnt coffee with which the proper quantity of sugar had been mixed. A few small pots and cooking basins completed the outfit. The business of camp life was equally simple. In the morning before mounting, black coffee and bread were served. Breakfast was eaten between 11 and 12 after a ride of a few hours, and a second substantial meal was prepared at night after establishing camp. Except for small supplies of corn (maize) obtained at long intervals at some farm house, the mules subsisted on the leaves of the bamboo and other tender foliage which they found along the route. Water and wood for the camp fire were everywhere in abundance.

*August 17th.*— There was a heavy white frost on the ground at Rio Negro at an early hour this morning. We set out promptly for the south, keeping track of the distance traversed by means of pedometers. A mule pace in Brazil is reckoned at 0.72 meters (2.36 ft.). The mule trail from Rio Negro to Lages traversing some thirty-six rivers and streams was cut through the forest in the middle of the 18th century as a military necessity (V. da Rosa, 1905, p. 265-266). As far as the Rio Laurenço, the route lies over shales and yellow pebbly sandstones carrying an occasional erratic block. Beyond

this point the road enters a heavily wooded district of moderate dissection with flat-topped interstream areas. We camped for the night near the road 2.3 miles south of a small settlement called Sepultura.

*August 18th.*— It was so cold at midnight that one of the camaradas made coffee with which we were served. At this hour a pan containing water was coated with a thin sheet of ice. From this camp to the Rio Contagem the route traverses a soft sandstone formation. Just before halting for breakfast at 10 a. m. we passed a shaded mud-puddle covered with a thin film of ice. These occurrences of frost and ice I note particularly because they were so contrary to my preconceived notions, based upon the imperfect accounts in North American geographies of the winter climate of even this elevated region in south Brazil. Apparently horizontal beds of deeply weathered sandstone continued to form the surface rock as far as camp No. 2 on the headwaters of a small stream, the Rio São João, a north flowing branch of the Rio Negro. The gentle descent from the plain to camp lay through a forest of Araucaria, tree-ferns, and a graceful bamboo with long curling tips.

*August 19th.*— The night was cold again, with frost on the ground and ice in the camp dishes at an early hour this morning. Shortly after leaving camp we traversed a plain with large areas of dead brakes, scattered palms, and tree-ferns. Araucaria is however the most abundant forest tree; there are large tracts of it, and many young trees are in evidence. For over a kilometer the path led through a dense growth of tree-ferns, taquara or bamboo, Araucaria, and large imbuías (*Canella imbuia* of Brazilian writers) with numerous mud-holes crossed-ridged with the pilões made by mules, through which our train of animals wallowed with extreme slowness. This jungle suddenly gave way to a wagon road on good ground, the sign of approach to some German or Polish settlement, of which however we saw nothing. Along this route we came upon a fine example of the tall Brazilian sassafras tree (*Nectandra cymbarum*), standing alone in the forest. Descending through swampy places of the wet-wood type we entered another forest of Araucaria. Tree-ferns partially hidden on the edge of these forests or standing in the more or less open growth of tall trees were in sight most of the day, but no rock exposures were seen and no pebbles bestrewed the trail which seems to have lain over decomposed shales. Here and there in the valley bottoms two or three huts were encountered, around which were pigs, a few sheep, cattle, and horses. We camped beside a stream on the soft spongy ground of tree-fern growth in the forest.

*August 20th.*—The night was cloudy with a little rain and consequently warmer than on the two previous nights. We found that we had gotten on to the road leading over the Serra do Espigão, the very route we meant to avoid because of the Bugres, but quickly resolved to keep on. After proceeding at a painfully slow pace with many uncertain turns through the forest we halted at a distance of not more than 3.2 kilometers for breakfast in a piece of open campo surrounded by the now dripping forest, our way having led over vales and ridges about 100 feet high and through tree-fern swamps. More native huts appeared at about 5 kilometers from last night's camp. At about 6 kilometers from the camp we encountered a chert bed on a hill south of a hamlet. Under this bed, at a river crossing immediately north, there outcrop green shales. We got into camp on the bank of a small stream the valley of which is excavated in a yellowish green shale. For an hour before reaching this camp, the flat sky-line of the Triassic escarpment could be seen ahead on the south. Some huts near camp were built of hewn boards and hand-made shingles, with the usual open windows. This place is Chaxim. There was a broken down cross and the remnants of a fence along side our camp, enclosing the burial place of some one killed by the Bugres. All travellers on this road we observed went armed, an example which we followed.

*August 21st.*—We got off early from camp as the manuscript map in our possession indicated that we were now near the base of the trap escarpment and should make the pass over the Serra do Espigão before noon. The road led over some low hills of greenish shale near the beginning of the ascent. Shortly before the climb began we came to a few houses south of Chaxim, at one of which, a store kept by a German, we found a bugreiro, or sort of special police, armed with a cavalry sword and a double-barreled horse-pistol, whose evident business it was to accompany parties over the pass. The ascent of this pass, only some 1,200 feet above our base at the store, was so steep as to oblige us to dismount, and was made in such a rush with all revolvers drawn, that geological observations were, despite the frequent exposure of ledges, neither advisable nor clearly made.

As is usual with South American mule paths the way led up the steep spur in preference to following one of the adjacent creases of the slope, since by so doing the minimum of mud and water is encountered at all times of the year. The escarpment below the crowning trap sheet is mainly sandstone of a reddish tinge which succeeds the green shales at the base. The chert beds before mentioned apparently

correspond with the Estrado nova shales of Dr. I. C. White, while the beds of sandstone in the face of the escarpment reddish below and light colored above correspond with his Rio do Rasto and São Bento beds respectively.

The trap crowned pass of the Serra do Espigão is separated from the main mass of trap on the south by ravines parallel with the escarpment, somewhat as in the annexed sketch of the profile. (Fig. 24, p. 93). The summit where crossed by the trail gave an aneroid reading of 3,950 feet. A new cross by the roadside at the southern side of the first ravine marked the spot where but a few weeks previous a Brazilian had been killed by the Bugres. Of these savages, however, we saw none nor were we molested. Our bugreiro left us at a point near the cross and returned to his post at the base of the escarpment. On passing the summit I noticed fresh ice crystal marks in a dried up mud-puddle. We descended at once the south slope of the ridge, passing the lower contact of the trap on the sandstones to an open campo watered by the Lageado liso, a small stream so named, in common with many in Brazil, from the flaggy beds in its channel and banks. The tilted attitude of a band of beds in the valley of this stream suggested faulting parallel with the escarpment, but I was not able to determine by the elevation of the base of the trap on the opposite side of the valley the occurrence of a displacement of this plane of reference, though it was my impression that the trap in the Serra do Espigão lay higher. From the Lageado liso the ascent is gradual but steadily upward to the top of a broad tableland of trap giving aneroid readings of 4,050 to 4,100 feet elevation some 6 kilometers south of the Lageado liso. At 8.6 kilometers some farm houses appeared about which were fields enclosed with stone fences. We descended into the valley of Passa dois on the south and went into camp. Numerous poles set upright in the ground showed that here the pack-trains halt for the night.

*August 22nd.*— There was a heavy frost last night. Between one and two kilometers south of camp red sandstones crop out with a northeast dip. Reaching the Rio Correntes at the noon halt, the route continued on trap to the camp for night on a small stream, the Rio das Pedras, near a farm house where were pigs and cattle in fields enclosed with rail fences.

The surface of the basalt traversed in this day's journey varied much in the degree of decomposition. For long distances there was good hard rock with a thin brownish crust of weathered products. Between these stretches along the road the rock was weathered down

to a deep brown earthy mass, and in small patches I saw reddish, and in one place, greenish clay. Bales of spherical separation appeared here and there and often the road led the mules between large angular blocks which bestrewed the hard trappean surface. The contrast between this thin coat of weathered trap and the deep beds of decomposition forming the *terra roxa* in São Paulo is very striking.

The Brazilian pine, *Araucaria*, occurred in small patches here and there and many young plants pointed to favorable conditions of growth for the species. An occasional Maté tree appeared along the trail, evidently due to the droppings from some passing caravan. From this high plateau there was a good view of a high trap range of tabular outline in the distant northwest, the prolongation of the Serra do Espigão extending towards Porto da União. The wooded surface of the range concealed all the rocks, but the triple terraces of the mass presumably signify a three-fold division of the trap sheets of which it is composed. Between our position at Corisco and this tabular mountain there lay an extended lower surface, the deeply dissected basin of the Rio Correntes.

Along the mule path, we passed several small grassy pools, occupying depressions partly enclosed in the trap. In at least one instance a pool lay on the upper side of the road and the water was held in by a barrier of mud and gravel accumulated in the road by wash from the descending grade on either side to the sag by which the drainage normally overflowed. The surrounding gramineous plants displayed the brown color of winter. The fine green grass of one of the pools had attracted to it a domestic horse which stood up to his knees feeding, evidence that the bottom was floored with probably the same stiff residual clay which later I saw in an excavation in one of these basins. On this monotonous succession of trap uplands of nearly uniform structure the trivial relations of the life which found a place upon them became matters of more than passing interest. On the muddy bottom of the rivulet which flowed past the evening camp I found a small fresh-water mussel resembling *Unio* crawling along with the open edges of the valve down so as to leave a deep narrow groove in the mud. The trail was sinuous and ended in a burrow where the mollusc pushed under a cover of mud. I should have assumed, had I not seen this animal at work, that the trail, as have been so many found in the fossil state, was to be ascribed to some gasteropod.

*August 23rd.*—The morning broke cloudy with rain threatening, for in this latitude on the trap plateau the distinction between a dry

winter season and a rainy summer is not so clearly recognizable as it is farther north in São Paulo. On proceeding some three kilometers through a forest of Araucaria and tree-ferns we heard a loud reverberating roar in the tall woods, a noise which my Brazilian companions announced to be that of an onça — the jaguar. With drawn revolvers they started at once into the woods in the direction of the unusual caterwauling sound, which certainly seemed to come from a large and powerful cat. From my post with the pack-train I heard their shots and presently the crash of a body falling through the trees. They had shot and killed a large howling monkey or alouatte (*Myecetes*), a red-furred specimen measuring about four feet from the nose to the outstretched end of the long prehensile tail. Our experience with this well-known monkey recalls the Italian proverb: —

La sera lione,

La mattine babbione.

Travellers in Brazil speak of the nocturnal howls of these monkeys but we heard their cries but twice and then only in the early forenoon.

We were soon led by a well-beaten track to make a detour from our proper route through the forest. This led us to an isolated cattle and mule ranch, whence we were directed to the main road to Corytibanos.

Our path lay through a more or less open growth of Araucaria broken in a valley by numerous stumpy palms, known as Butia. Cattle grazed on several open valley floors. On the open interstream areas we passed many of the small pools or lakelets and in one of them with the brilliant green grass before mentioned lay a dead horse whose struggles were evident from the disposition of the vegetation near his feet. I note this as an instance of how large herbivorous mammals may be tempted into swamps and under favorable geological conditions become fossilized. The animal in this instance had not become mired but probably had fallen ill from the unwonted diet. About an hour after noon we regained the thoroughfare near a cluster of houses with a monjolo or farinha mill, where we halted and cooked breakfast, on the bank of the Rio das Pedras. The basalt traversed this morning displayed many cavities lined with zeolites, fragments of these minerals glistening in the mule path every few yards. The same dull dark brown hue of the thin trappean soil appeared as farther north but I noted in one section where we descended to a stream channel a reddish rusty zone of decayed rock underlying the superficial brown coat of rock which was here about one meter thick.

The day came off clear and fairly warm, giving from one or two of the trap elevations distant views to the north and south of level sky-lines broken only by an occasional remnant of a still higher basalt sheet in the series over which we were travelling. The surface past over this morning was one of rather immature relief with no deep, steep-sided gullies or ravines. Numerous small streams showed short falls over trap ledges and rapids of no great length, manifestations of streams actively at work and far from being well graded. While we were halted on the Rio das Pedras a troupe of forty mules came along bound southward. After searching in the nests of quartz which here beset the decomposed trap for other minerals, we set out and went into camp for the night on a small rivulet (Rio Ponte alto) at the base of a steep trap slope surrounded by the araucarian forest.

*August 24th.*—A puma came into camp in the night at about 1 o'clock and drove our dog into the tent. Alfredo fired twice at the glowing eyes of the animal but missed him. This is the sole instance in which on this expedition we were disturbed by any large nocturnal cat. During the day we saw nothing of the mammalian fauna of the forest. The tapir must be abundant in the deep recesses of the woods along the streams. We saw hanging on the wall of the store the skin of one which had been shot at the foot of the Serra do Espigão. After a ride of an hour and a half from camp we forded the river Marombas whose valley floor with a floodplain of some width lies fully 300 feet below the surrounding trap plateau. There is a small settlement of houses here in the garden of one of which I noted a palm tree and a large prickly pear cactus (*Opuntia*) about ten feet high. The road from this point onward crosses a succession of trap ridges and valleys, with a relief varying from 200 to 300 feet, as far as the broad elevation of cleared ground on which stands the pink and white village of Corytibanos. Here we halted for breakfast by a spring on the outskirts of the place and having rested on the warm dry grass and procured an additional supply of provisions including some bread and butter, proceeded southward along a mule path with bridges over small streams to a camp for the night. On the way we encountered in the south bank of a stream valley about 100 feet in thickness of red beds in a clayey state overlain by trap. Quartz in radiating nodules abounded in the trap traversed today, but little of geological interest could be noted in the monotonous ride over the basalt surface other than the minor variations of the topographic relief. Araucaria remained the dominant forest tree, while tree-ferns and bamboo could be seen near or along the water courses. Beside our camp, in the low

ground a few kilometers south of Corytibanos, frogs abounded in small grassy swamps or lakelets. One frog had a weak peep, another a rattling croak, and one a cry like that of a baby. The great number of these small lakelets on the trap plateau with standing sweet water even in the dry season of the year is evidence that the rock crevices are well supplied with water. The occasional rains which we encountered and the impervious nature of the deeper rock together with the residual clays which form the bottoms of depressions unite to keep much water in sight at the surface. Yet there is a great variation in the amount of permanent moisture present in the soil in the several habitats of plants, the quantity increasing from the hills towards the narrow valley floors as is exemplified in the distribution of the tree-ferns and the bamboos. We saw grass or forest fires yesterday and today in distant broad valleys.

Another puma was reported in sight by the men just as we retired. The first snake which I have so far seen in Brazil, a small bright graceful green snake, was encountered on one of the little bridges south of Corytibanos. *Araucaria* continues to be the dominant forest tree. With it and rivalling it in size is the scraggly imbuia whose bole attains a diameter of 3 feet or about a meter. What impressed me most concerning the trees of south Brazil was the small ovate leaves with entire margins which so many of them possess. The broad leaved oaks, maples, tulip-trees and other forms familiar to the North American as existing species with precursors occurring fossil as far back as the Cretaceous are here wanting. So far as leaf evolution goes these simple outlines recall the forms which are so characteristic of primitive types in all organisms.

On the north bank of the small stream on which we camped this night there was exposed a bed of red shale traversed by small vertical faults with downthrow in each case on the west. This stream, the Lageado penteado, is a branch of the Rio Canoas. The name Lageado applied to streams like that of Lages given to the town to which we were bound has reference to the slabs of sandstones which abound in this region and "pave" as it were the beds of the small streams.

The Canoas river has shifted its course in the degradation of the region down the dip of the formations so as to hug the southern edge of the basalt.

I saw no fossils in the red shales but found some concentric conchoidal fractures or joints.

*August 26th.*—Light showers during the night. Ant-hills and

red soils are not so common on this Triassic area as on the north in Paraná and São Paulo. The basalt has disappeared from a large tract about Lages without leaving any noticeable trace.

At 9:25 A.M. we came to the Rio Canoas which is here a broad deep stream over which our pack-train was ferried on a platform supported by four dug-out canoes and held to its course by a wire cable. On the upland we passed the hamlet of Canoas with oxen ploughing. Shortly before noon we descended a steep slope to a stream crossing with red shales dipping north in the bank. Farther on the mule path traverses a dike about seventy-five feet wide cutting the sandstones. This dike is heavily charged with fragments of several rocks and minerals evidently brought up from below. About a mile farther south a narrow dike about one foot wide occurs along the trail near a small stream. About a mile farther south there is a short low ridge on the east of the road with small conical spurs and buttresses of inclined beds on its north side. On approaching this point on the road with a slight rain falling thousands of winged ants flew over the campo up to fifteen feet in the air and for some reason chose to collect behind my head in great numbers. On catching up with the party I found the tent pitched in a clump of bushes at the western end of the ridge just as a steady rain set in for the night.

The small lakelets so characteristic of the trap surface also occur in the sedimentaries south of the escarpment. Here the depressions appear to mark the site of springs. From the dike southward the dip is southerly and probably S. W. There is a small anticlinal fold near this camp with axis NNW-SSE.

*August 27th.*— It rained nearly all night and until 7 A. M. We rode southward across the bleak campo to a descent over sandstone beds which brought us, after a journey of fourteen days from Ponta Grossa, into a broad irregular valley in which Lages lies.

*August 28th.*— The light brown Triassic sandstone under a red shale bed north of Lages is quarried for building stone and flagstones. No fossils other than wandering trails were to be seen in the sandstone. Certain greenish shale beds pass laterally and obliquely to the stratification into red beds, and well-defined green-walled joints in the red beds show that the green color is locally a post-depositional alteration of the deposits. In the afternoon we returned northward, to the locality of the dike bearing inclusions, for a more detailed study of that rock.

Ant-hills about fifteen inches high bestrewed the surface of the Triassic sedimentary tract. As usual most of the hills had been

broken into by some burrowing animal and many colonies were abandoned. This cycle of change must several times have worked over the surface materials of the campos of Brazil and facilitated the work of erosion by winds and rain.

When it is recalled that a large insectivorous fauna including the anteaters, Myrmecophagidae (*Vermilinguia*), inhabit the ant-occupied surface of Brazil and that this group is specialized with reference to the ants and that traces of this organic adaptation go back to Pliocene times, it is evident that ants and anteaters have exercised an important function in the geologic processes which have worked together in the evolution of the surface deposits of Brazil. Fossil ants are numerous in the Oligocene beds of Florissant in Colorado (Scudder) and anteaters appear in the Miocene Santa Cruz formation of South America, dates which are as far back if not earlier than the beginnings of the present surface deposits of the Brazilian highlands.

*August 29th.*—The road northward from the camp at the dike passed over alternating beds of red shale and yellowish to reddish sandstones, dipping gently to the northwest towards the southern margin of the trap sheets, whose escarpment, as far as it could be seen, extended in a northeast-southwest direction roughly parallel to the strike of the underlying sediments. From the top of one of the monoclinical ridges between the Rio Ponte alto and the Rio Canoas, this escarpment could be traced to the eastern horizon where a conical outlier stood out in clear relief as a monument to the erosion of the trap cover which formerly extended over the Lages area.

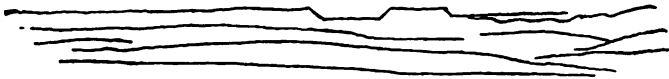


FIG. 4.—Field sketch of the trap plateau northwest from Rio Marombas in Santa Catharina.

The monoclinical structure of the sediments results in a series of ridges with steeper faces on the southeast and longer gentle slopes to the northwest. At about twelve kilometers from camp we crossed the Canoas River, and continued northward to the north bank of the Rio Ponte alto where we camped by a covered bridge. The stream at this point flows in a channel about twenty feet deep over sandstones with an active drainage.

*August 30th.*—After a march of an hour and fifty minutes from camp we passed over sandstones striking northwest and dipping about 15 degrees to the northeast. About forty-five minutes later we

surmounted the dissected trap plateau at an elevation of some 700 feet above the valley of the Rio Ponte alto. The broad valley of the Rio Cachoeiras which next succeeds exposes a bed of sandstone in its banks below which lies a trap sheet over which in turn it flows. About ten miles north of the river we camped for the night near a frog pond between two of the mule bridges which mark the approach to Corytibanos.

*August 31st.*—An hour's ride from camp brought our cavalcade again to Corytibanos, at which point we took the road northwest towards São João *en route* to Porta da União on the Iguassú. For several miles along this route we traversed campos with a scattered growth of the the araucarian pine and then of the Butia palm. One deeply weathered trappean hill bore numerous lakelets or lagoas bordered by tall tufts of grass. Blackened heads of trap rock cropped out over the surface of the inosculating ridges which separate these solution-basins. At noon we halted beside a small stream whose milky waters were without apparent cause since it had not rained. On resuming our march we shortly heard the roar of falls in the course of the Rio Marombas on the left in the forest where the river tumbles over the bedded traps. The river was crossed on a balsa or ferry, a sort of raft supported by four or five wooden canoes. (Plate 17). A forest fire was burning on the east bank of the river. After traversing two deep valleys and a broad hill of dry campo we camped on another small milky stream in a cattle country. The milkiness of these small streams was possibly due to cattle wading in them. The day was warm, and beetles, butterflies, and dragon-flies were out fluttering over the muddy flats of a stream at noon.

*September 1st.*—About an hour and a half after leaving camp this morning, we came to the Rio Correntes which was forded on a trap bottom. After proceeding for an equal length of time we crossed another broad shallow stream with rapids, the Rio dos Patos, also on trap. We followed up the right bank of this river in a northwest direction until nearly noon when we came to a *coboclo* hut in the forest, where a woman gave us directions. Our halt for breakfast at the noon hour was beside another small sluggish milky stream. Several of the solution-basin lakelets were passed during the forenoon. As the trail was not distinctly marked from the paths leading from one hut to another in this forested region, much of the afternoon was spent in seeking directions. A large forest fire at one time was raging to the west of our position. Fires in the standing clumps of dry dead bamboo burn with great rapidity. At length we entered

a burnt over tract of *Butia* palms, where beside one of the milky streams we encamped for the night. My mule had given out during the afternoon and was towed into camp tied to the tail of a sound animal. In the forest along the trail I observed a small wild tobacco plant from four to five inches high, which our head camarada termed "fumo dos Bugres." A pair of papagaios flew over the camp at sunset and a few mosquitoes buzzed about our fire of araucarian knots.

The Brazilian pine (*Araucaria brasiliana*), when young, resembles in its branching habit the other members of the Coniferae; but it scarcely attains full height before its branches become crowded towards the top by the dropping off of the low ones. An old tree thus presents a clean bole with usually one but sometimes two great whirls of branches at or near the top and recurved upwards. Upon the fall of a dead tree frequently as much as ten feet of the upper extremity of the prostrate trunk is a mass of highly resinous knots which remain undecayed for years after the surrounding wood has disappeared. In the wettest weather a fire of these knots can be quickly made. Along the line of railway in southern Paraná the knots are used for fuel on the locomotives, and bins of these combustible, inflammable stores of the araucarian forest are frequently seen at the railway stations. The young trees when not over four to six feet high present an appearance very unlike the adult form with its smooth bole and palm-like apical whirl of branches with leaves growing in large clusters at the ends of the branches. The young tree is thoroughly covered with broad pine leaves resembling small Cordaites. On the branches these leaves point outward and upward, but those on the bole which are still larger bend sharply downward at the point of attachment and present sharp needle-like points to stay the progress of any small climbing mammal which would find equal difficulty in reaching the main stem of the tree by descending one of the branches. This apparent adaptation of the foliage to protection from arborescent animals in the young stage of the plant is a device the use of which I did not observe, for on account of the nocturnal habits of most of the animals of the Brazilian forest and the noise made by the approach of our troop of mules we saw during the day no wild mammals whatever.

*September 2nd.*—For over two hours after leaving last night's camp, our route lay through the forest on the south slope of the Serra do Espigão. About 11 A. M. we emerged on a more travelled trail along which we passed several huts. Late in the afternoon the sick mule lay down and we were forced to abandon the animal, as our

slender stock of provisions obliged us always to make rapid transits of the long stretches between settlements. We camped on the headwaters of the Rio dos Patos, the bed of which abounds in agate pebbles derived from the trap.

*September 3rd.*—The mule road ascended rapidly from camp to elevations by aneroid of 4,000 feet on the crown of the northwestern arm of the Serra where there is a small settlement and a store. Small streams continued turbid. The interstream areas were weathered into deep pits with numerous bogs.

*September 4th.*—The march to the northwestward today lay at a high level on the northeast side of the crest of the Serra, a rolling country partly open campo and partly occupied by pine. Inhabitants became more frequent and pack-trains indicated the proximity of the terminus of the railway. At half-past two we heard the whistle of a locomotive and at 5 P. M. came out upon the line of the railway in construction from Porta da União southward over the trap plateau to the Rio Peixe. At 9 o'clock at night we found our way into São João, from which place on the following day we returned by train to Ponta Grossa leaving the pack-train to come along at its own gait.

*September 15th.*—With the view of studying more in detail the tillite beds on the banks of the Rio Jaguaricatu in northeastern Paraná, Dr. Oliveira and myself with a small camp outfit and one camarada went from Ponta Grossa to Sengéns Station on the newly constructed railroad. While absent from our camp on the 16th, our tent and most of the contents were destroyed by a fire. Fortunately none of my instruments or notes were lost. Through the courtesy of the railway officials we slept in a railway storehouse that night and the following day returned to Ponta Grossa.

*September 19th.*—In company with Dr. Euzebio Oliveira I returned to Rio Negro with the intention of exploring the tillite beds along the road between that town and São Bento. It was on this occasion that Dr. Oliveira found a bed of fossiliferous marine shales between boulder-beds on the south side of the Rio Negro. About two legoas above Rio Negro there is a water-fall where the Ribeira das Rutes falls over a hard bed of tillite.

From Rio Negro I returned to Curitiba *en route* to Paranaguá, whence by steamer I reached Rio de Janeiro. The delay in waiting for the steamer was utilized at Curitiba and at Paranaguá in examination of the superficial deposits and studying the topography, the results of which studies are embodied in the account of the geomorphology of this part of Brazil.

From Rio de Janeiro, again through the intermediation of Dr. Derby, I set out on October 12th for the planalto of São Paulo to examine the tillite beds on the railway line between Itaicy and Piracicaba. Dr. Cardoso, chief of the São Paulo Geographical and Geological Commission detailed Dr. Pacheco of that bureau to accompany me. The excursion was made with a railway automobile, over the part of the line traversing the sediments. This afforded every opportunity for a rapid reconnaissance. On returning to Rio de Janeiro, I sailed from that port on October 24th bound to Laguna for the purpose of examining the Permian section of the Tuberão Valley. Dr. Euzebio Oliveira joined me at Paranagua. On this and the return voyage the necessary delays in waiting for the small coasting steamers gave opportunity of making observations upon shore-line changes and the general features of the Serra do Mar at São Francisco, Itajahy, Florianopolis, and Laguna.

While waiting for the steamer at Laguna a study was made of a sambaqui or shell-mound forming a small terrace on the flank of the granite hill at the south end of the town. The top of this deposit is about 100 feet above sea-level and has been dug into as a local source of lime. The deposit is composed principally of a small lamelli-branch, in parts of the mass somewhat cemented together. In the upper part of the heap I found a stone-axe, fragments of a fine-grained rock evidently used for opening shells, fish-bones, mammalian bones, and part of a human skull, as well as portions of a large sea-urchin, all indicating by their leached condition considerable antiquity. At a lower level a large *Ostrea* was abundant. The deposit has a rough stratified structure but nothing like that induced by deposition beneath moving and assorting currents of water. Neither in the topography nor in the structure were there characters seeming to demand other than surface accumulation for the origin of this shell-heap. The dead shells of a recent large snail, *Bulimus*, were rather abundant on the surface of the kitchen-midden, and the old shells were sliding down to the present beach. Professor Dixon has kindly written a note on the collections I made at Laguno, (p. 132).

*Voyage from Rio de Janeiro to Talcahuana. November 25th, 1908.* The journey from Brazil through the straits of Magellan to southern Chile was begun today by sea on the steamship *Oravia* of the Pacific Navigation Company, with stops at Monte Video, Punta Arenas, and Coronel.

*November 29th.*— At Monte Video. Two partly dismantled barks lay at anchor in the harbor, having fallen back to this port for repairs

after an encounter with ice off Cape Horn. Captain Wm. B. Oakley of the *Oravia* informed me that after the Valparaiso earthquake of 1906 there had been an unusual amount of ice in the sea about the southern end of South America, the ice having been dislodged from glaciers by the earthquake, so it was believed. This report agrees with the effects reported by the late Prof. R. S. Tarr arising from the Alaskan earthquake of 1899, which caused much disturbance of the glaciers on the Alaskan coast and warrants the belief that at least local earthquakes may greatly accelerate the flow of glaciers.

*December 4th.*—We entered the straits of Magellan during the night. To the voyageur entering the straits from the east the high barren plains on the north and the treeless low-lying plain of eastern Tierra del Fuego on the south alike recall the plains of glacial Cape Cod veneered with glacial drift. Between Elizabeth Island and Punta Arenas there are some irregular terraces of varying height, appearing more like glacial contemporaneous terraces than the horizontally levelled benches cut by waves. Back of the town of Punta Arenas there is a deep gully at the mouth of which lies a prominent deposit forming a rounded southward slanting ridge, on the seaward slope of which the town is mainly built. There is a remnant of what appears to be a stream delta north of the town, now forming a terrace. The *Pour-quoi-pas* of M. Charcot's French Antarctic expedition lay at anchor off the town.

The passage from Punta Arenas to Cape Holland was made after 4 P. M. but permitted a general view of the profile of the Andes rising above the plains of Tierra del Fuego. (Fig. 5.) It is evident



FIG. 5.—Generalized profile of the Andes on Tierra del Fuego, showing the arching up of a once baselevelled but now deeply dissected mountain mass. It is not here intended to interpret the steep western descent into the Pacific Ocean.

that here as far to the north the peaks and valleys are carved out of a theoretically smoothened surface of the deformed rocks composing the folded chain. It is conjectured that this now warped, once baselevelled, surface passes beneath the Tertiary and Pleistocene deposits of the plains of Tierra del Fuego, forming the platform on which these less ancient deposits repose. Towards the western margin of

the Andesian uplift, the dissection of the surface is more complete, and the descent to the bed of the Pacific Ocean is steep.

*December 8th.*—The *Oravia* put into Coronel for a supply of coal. The mines at and near Coronel are the most important on the coast of South America. The principal outcrop of coal is inland, some distance from the shore but the workings follow the coal beneath the sea. The beds in which the coal occurs are regarded as of Eocene age. (Sundt, 1908, p. 37-44). The coal is bituminous and is described as bright and clean but light. The Arauco Company has produced from its mines as much as 200,000 tons per annum. The coal is extensively used by steamers plying the west coast and in the locomotives of the Chilean railway (Alcock, 1907, p. 85).

Captain Oakley of the Pacific Steam Navigation Co. expressed the opinion that the coast at Coronel has risen in recent years. An old wreck partly buried in the beach skirting the south side of the point on the north of the anchorage, according to his observation now lies higher than when he first saw it. I note the opinion as a matter for further investigation.

While the steamer was taking in coal I went in a sailboat to Lota, a small port about four miles south of Coronel, where coal is also mined. A conglomeratic sandstone here crops out, the scattered pebbles and massive bedding of which strongly suggests the transportation of the pebbles by ice. In my hasty examination of the rock I was unable to find striated pebbles. It should be noted in this connection that Darwin (1846, p. 69) described "great boulders of granite and other neighbouring rocks, embedded in fine sedimentary layers" in Tertiary deposits along the coast of Peru. Back of Coronel there are at least three terraces in the bed rock but whether due to differential weathering or marine erosion at different levels I was unable to determine. Along this coast towards the Tumbres Peninsula there is an uplifted baselevelled surface forming a narrow bench cut back and cliffed by the sea at the present level, with subdued remnants of higher rock masses rising above the terrace as in the case of the Paps of Bio Bio. This bench must be early Pleistocene or late Tertiary in date. Narrow steep ravines crease the cliff face; but practically no stream-cut channels cross it with their mouths at sea-level. All the small vales which traverse the bench are hung up at the seaward edge by reason of the cutting back of the terrace by the sea. This bench is probably to be correlated with a well-defined bench of erosion at Corral on the south but is much higher above the sea.

We entered Concepcion Bay on December 8th, and on the 9th I went ashore at Talcahuano. I spent several days in the vicinity of Concepcion examining evidences of change of level. As the results of my observations are given in a subsequent chapter I make mention here only of some unrelated geological details.

On December 11th, while yet in bed, at about ten minutes past seven, I felt a slight quivering followed by a sharp lurch of the hotel. The wooden framework of the ceiling cracked and creaked. The daily press stated that at 7.10 a short but violent shock was felt. Again on the 13th of December while in Concepcion, the daily press reported during various hours of the night subterranean noises accompanied by a shock at 12.40 A. M., which caused some alarm. I was awakened at about 1.35 A. M. by what at the time I thought was the fall of an object in the room below; meanwhile I heard a rumbling noise sounding like that made by street cars. The destruction of Valparaiso by the earthquake of August, 1906, has made the inhabitants fearful of a repetition of such violent earthquakes, particularly at Concepcion whose ancient site at Penco on the shores of the Bay has been the seat of the most famous earthquakes in the annals of Chile. The practice of the Spanish in South America of leaving a site more than once damaged by earthquakes has much to recommend it. In the case of Old Concepcion or Penco, twice destroyed by earthquakes and inundations from the sea, the site was mainly on a marsh behind a barrier beach filling out an indentation of the coastal hills, a location, owing to the soft nature of the recent alluvial deposits, likely to be severely shaken by earthquakes. The new city of Concepcion stands on a plain of Pleistocene alluvium mantling much disturbed sandstones which here and there rise as low hills through the plain. That this city has escaped destruction so far from earthquakes is seemingly due rather to the failure of local violent shocks than to its location.

On December 13th, I visited Penco, the site of ancient Concepcion. Since Darwin's time the construction of a railway along the shore of the bay has led to the partial demolition of the old Spanish Fort, the seaward portion of the walls only remaining. (Plate 4). Of what I presume to be this building, Lyell states: "It has, however, been ascertained that the foundation of the Castle of Penco was so low in 1835, or at so inconsiderable an elevation above the highest spring tides, as to discountenance the idea of any permanent upheaval in modern times, on the site of that ancient port; but no exact measurements or levellings appear as yet to have been made to determine this

point, which is the more worthy of investigation, because it may throw some light on an opinion often promulgated of late years, that there is a tendency in the Chilian coast, after each upheaval, to sink gradually and return towards its former position." (Lyell, *Principles of geology*, 11th ed., New York, 1887, 2, p. 156). I found this view still current at Talcahuano, and it is evident from the view referred to that no marked permanent change of level has affected the ancient ruin on the beach at Penco since it was constructed.

The railway from Concepcion to Penco traverses an outcrop of coarse, waterworn conglomerates at Paradero de Santa Ana, evidently a member of the Tertiary series which underlie the plain between the Coastal Cordillera and the ridge of crystalline rocks which form the Tumbres Peninsula on the seaward side of the Bay of Concepcion. In the bank of the bay shore immediately south of Penco, coarse gravels composed of pebbles of crystalline rocks and occasionally large rounded stones crop out in the railway cut in marked unconformity upon sandstones. The change from the blue color of the gravels at the base to orange at the top of the bluff is evidently an effect of weathering now in progress. Certain portions of the pebble beds contain stones a foot or more in diameter. The deposit is mainly stratified with flattish ovoid pebbles lying in the planes of bedding. In the lower part of the exposure the paste of fine material is less obvious than in the upper portion. Lenticular beds of sand and finer gravel appear at intervals in the section, pointing to intermittent or shifting currents or streams. From its general relations and want of consolidation I supposed the deposit to be of Pleistocene date and possibly not older than the bench which at about the same elevation can be traced around the seaward face of the Tumbres district at the Paps of Bio Bio. If this correlation be correct the deposit may be of marine origin, but no fossils were seen in any part of the section.

On the exposed face of the gravel bluff loose materials were sliding down in such a manner as to afford an instructive example of the post-depositional striation of pebbles. A large rounded cobble protruding from the section (Fig. 6) was well striated on its exposed surface by pebbles sliding down over it in the wasting of the upper part of the bluff. I observed this process in action, and it showed the necessity of taking every precaution in accepting detached striated pebbles as evidence of glaciation.

On December 18 I left Concepcion for Valdivia to examine the shore-lines of that district for the reason that Darwin stated that here he

found no local indications of elevation. The results of this journey are contained in my remarks on the coast of Chile. (p. 132).

*December 23th.*— Being due at Santiago on Christmas day I left Valdivia, journeying northward by rail through the Longitudinal Valley of Chile, with a stop at San Rosendo to make a study of the Pleistocene terrace deposits on the Rio Bio Bio. In ascending the valley of the Calle Calle through the gorge in the Coastal Cordillera, the crystalline schists were observed to have the same steep eastward dip as in the Tumbres Peninsula in the latitude of Concepcion. The rock-bench which is so pronounced a feature about the shores of Corral and the Valdivia River along the Calle Calle above Valdivia becomes suffused with gravels, presumably Pleistocene. Pebbles of nonschistose rocks abound, indicating the derivation of the materials from the Tertiary and volcanic rocks within the Longitudinal Valley.

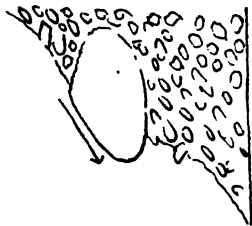


FIG. 6.— Section showing how exposed surface of a cobblestone became striated by gravels sliding down in direction of arrow; at Penco, Chile.

From December 25th, 1908, until January 5th, 1909, I remained in Santiago in attendance on the sessions of the First Pan-American Scientific Congress. I have published a brief note on the geological papers read at this meeting. (Woodworth, 1909).

Under the guidance of Dr. Phillipi, a visit was made to the Museum of natural history and to the Museum of the mining society. Among the collections of this Society I was shown several remarkably intricate examples of stones carved by the sand-blast. These were gathered on the surface of the desert of Atacama by Mr. Carlos Sundt. In some cases large holes had been eaten through irregularly carved fragments of rocks by this insidious process. Through the courtesy of Major Montessus de Ballore I was also permitted to examine the Seismological Observatory then in process of installation in the hill of Santa Lucia in Santiago. This is the principal station of the seismological service of Chile. From Santiago I proceeded to Valparaiso for embarkation on a steamer bound for Panama.

*The Valparaiso Earthquake of August 16, 1906.* While waiting in Valparaiso for the sailing of the steamship *Limari*, a day was devoted to a casual examination of the effects then visible of the disastrous earthquake of August 16, 1906. As has been so often observed in the downthrow of maritime cities by earthquakes, the

damage was most severe along the water-front where the alluvial deposit and made-ground imposed the thickest layer of loose unconsolidated material upon the bed rock. In this zone many buildings were completely levelled. Nearer the base of the cliff which partly separates the upper from the lower portion of the city, buildings stood with their walls cracked and cornices broken away but frequently otherwise safe for habitation. Upon the sloping ground above the line of cliffs where a superficial layer of weathered rock on the inclined surface had slipped down carrying buildings with it, and in the cemetery where similar conditions existed, the destruction was most pronounced. The reconstruction of the business houses along the incoherent ground of the water-front insures a recurrence of the tale of destruction when in the future the seismic movement affects in this vicinity the line of displacement which skirts the coast of Chile. From the studies of Dr. H. Steffen in the case of this earthquake the disturbance appears to have had its origin off Coquimbo, a sea-port 198 marine miles north of Valparaiso.

I was impressed with the fact that in a large number of the houses that were not completely destroyed the damage was at a maximum in the peripheral parts of the buildings; that though one or more of the outer walls were demolished or thrown outward, the internal walls and the inner angles of the floors were left standing in place unencumbered by fallen wreckage in such a manner that persons unable to leave these buildings would have escaped with their lives had they sought refuge during the height of the shocks in the internal corners of the rooms. I had occasion later to note instances of the same sort amid the ruins of Kingston, Jamaica, produced by the earthquake of January 14, 1907. It would seem advisable from this observation that houses in earthquake countries should be constructed with one or more sets of rectangularly intersecting, internal walls well united of materials whose period and amplitude of vibration as a mass is identical so that one end of the building will vibrate as nearly as possible in unison with the other. From the lack of this synchronicity and equality of lateral swaying the outer walls will probably be thrown off or toppled down but the central structure of buildings properly balanced, as numerous examples have shown, often stands and by a slight special construction adapted to the purpose, the internal angles of such intersecting walls might in many cases prove places of refuge and security.

This Chilean earthquake, coming at a time when the people of the United States were preoccupied with the calamities of the similar

great disaster which had but four months previous led to the destruction of San Francisco, has received such scant attention in North American scientific journals that the following notes taken largely from local accounts and the paper of Dr. H. Steffen of the University at Santiago are deemed worthy of record.

In Valparaiso the immediate loss of life was estimated at 3,000 persons and the wounded at 20,000, some of whom subsequently died in consequence of their injuries. Several hundreds of lives were lost in surrounding towns and villages. (Rozas y Cruzat, 1906.)

Owing to the lack of seismographs in Chile in 1906, the exact time of the earthquake is a matter of some uncertainty. At Santiago where there is an astronomical observatory the first sensible shock appears to have taken place 7h. 58m. 36s. P. M., August 16th, local time. Taking the longitude of Santiago as 4h. 42m. 46.4s. west from Greenwich, the initial shock was felt there at 0h. 41m. 22s. Greenwich mean time, midnight to midnight, August 17th. At Valparaiso whose time is 3m. 50s. later, the first shock is placed at 7h. 55m and at 7h. 56s. by several different time-keepers. The mean of the times at Valparaiso, 7h. 55m. 30s. makes the apparent time of the first shock at Valparaiso 44 secs. earlier than that at Santiago. The earthquake from various studies appears to have originated in a fault plane off Coquimbo about 228 miles north of Valparaiso. The seismographic indications as to the time of origin point to 0h. 40 m. as the probable moment of the primal great shock.

From the varied estimates of observers, it appears that in the central tract along the coast extending north and south of Valparaiso between the parallels of 28° and 39° S. L. there were two series of shocks separated by an interval of relative quiet. The first strong shock of exceptional duration, lasted from four to five min., while the second equal to or perhaps stronger than the first one had a duration of 1 min. or less. Outside of the epicentral region but one continuous series of shocks seems to have been noticed. (Steffen, 1907, p. 23). A vertical movement was distinctly recognized at isolated points between 38° and 36° S. L. with greater distinctness and precision on the north as far as the river Mante. Most observers judged the primal movement to be upward. Dr. Steffen obtained testimony to the effect that heavy objects in Illapel, Santiago, Talca, etc., within the central tract were thrown upward to a certain height above the base on which they stood, contradicting as he notes the statement of Dutton (1904, p. 148) that there never has been observed an acceleration sufficient to overcome the force of gravity. It may

be noted also that in the Indian earthquake of 1895 (Oldham, 1899), many large boulders were inverted on their sites in a manner demanding apparently their projection free from the base on which they rested.

The most important data gathered by Dr. Steffen has a definite bearing upon the controversy raised by the distinguished Austrian geologist, Professor Edward Suess, over the question of the uplift of the coast of South America accompanying earthquakes, a thesis set forth by Darwin and Fitzroy. Dr. Steffen was aware of the importance of critical observations made at once upon evidences of change of level of land and sea along the disturbed coast. From the information obtained he came to the conclusion that there can scarcely be any doubt as to an elevation of the coast from the mouth of Rio Mataquito to that of the Choapa along a segment of the sea-border corresponding to the area of maximum perturbation in which the seismic intensity rose to the degrees of VII and X in Mercalli's scale. This movement appears to have been greater on the north than on the south. The measurements most worthy of confidence in Dr. Steffen's opinion are 40 cm. at Llico, south of Valparaiso in about  $34^{\circ} 40'$  S. L. and 70 to 80 cm. at Zapillar, north of that city in about  $32^{\circ} 25'$  S. L. Señor Lorenzo Sundt, an experienced geological observer whom I met in Santiago, stated that in the bay of Valparaiso some 200 meters west of the pier of the Matodero at Portales, there was to be seen upon the rocks after the earthquake a white band composed of a small species of barnacle and of Algae of the Corallinacea forming a natural mark which at time of low tide was left uncovered for two feet above low-water mark, although before the earthquake it was not visible. Likewise a local officer of Portales who had observed the coast for eighteen years noticed after the earthquake that a rock, which he had not seen before appeared above the surface of the lowest tides. These stations which are composed of the solid rock are free from the doubts which affect the altered position of loose materials. The probable correctness of the contention of Darwin and Fitzroy that at times of great earthquakes on the coast of Chile there is an upward movement of the land seems now to be established; but whether this uplift is permanent is doubtful, since as in the celebrated case of Concepcion, I was informed when in that vicinity that it was the opinion of the naval officers stationed at Talcahuano that a slow subsidence is now in progress. As for the uplift of faulted blocks in relation to sea-level it is now well established and nowhere more pronouncedly than in Alaska by Tarr in the case of the earthquake of 1899 in which an

elevation exceeding forty-two feet was ascertained by indubitable evidence. But this case arose in a folded mountain-chain of recent development where uplift is not denied by Suess. The Coastal Cordillera of Chile is composed of an elongated horst lying outside of the folded chain of the Andes and the evidence of uplifts at the time of the Valparaiso earthquake of 1906 is therefore of especial interest in confirming the conclusion of Darwin and Fitzroy that an elevation of the coast may take place concomitant with an earthquake on this coast, though it does not prove that the coast has been permanently elevated by successive stages at long intervals in this manner.

From the information collected and published by Dr. Steffen, we also learn that no noticeable seaquake wave or tsunami was set up in that part of the coast which was the seat of the maximum seismic activity and change of level. At Constitucion and particularly in the bay of Talcahuano unusual movements of the sea, however, appear to have taken place. At Tomé on the eastern shore of this large shallow harbor at a time differently stated as a quarter of an hour and as an hour after the earthquake, the sea retired for about fifty meters, returning quietly to its place. This movement was repeated three or four times, the last two incursions being the greatest, covering a space of seventy meters. At Penco, the site of Old Concepcion, made famous by the number of times it has been devastated by earthquakes and sudden irruptions of the sea, similar phenomena took place. A wave rose to the level of the railway (Plate 4) along the beach and passed through the bridges and drains to the low ground behind, causing the inhabitants in their alarm to begin to take refuge in the neighboring hills; but the sea returned, so it is stated, to its normal level in less than ten minutes. (Steffen, 1907, p. 66-67).

The Valparaiso earthquake followed immediately upon a heavy earthquake on the submarine border of the Aleutian Island platform in 50 N. L. and somewhere between 175° and 180° of longitude E. from Greenwich according to seismometric determinations.<sup>1</sup> The mean of the determinations of the time at origin of this shock by Zoeppritz, 0h. 10m. 47s., and by the observatories at Florence, 0h. 10m. 35s., Laibach, 0h. 11m. 19s., and Tokyo, 0h. 11m. 16s., is 0h. 10m. 59s.

<sup>1</sup> Zoeppritz places the origin within 100 kilometers of 180° of Longitude from Gr. and the time as 0h. 10m. 47s.  $\pm$  20s. See E. Rudolph und E. Tams *Seismogramme der nordpazifischen und sudamerikanischen erdbebens am 16 August 1906*, Strassburg i. E. 1907. Professor Omori gives the origin at 175° +° E. L. and the time as 0h. 11m. 44s. G. M. T., midnight to midnight.

which may be taken as 0h. 11m. or about 29m. 10s. previous to the calculated time of the Valparaiso shock at origin.<sup>1</sup>

According to Benndorf the secondary preliminary or transverse group of seismic waves arrive at distances of 14,000 kms. after an interval of 30m.; according to Rizzo's later work, we may expect them to arrive as early as 29m. 30s. after the primal shock, or after a mean interval of 29m. 45s.  $\pm$  15s. It thus seems highly probable that the Valparaiso shock was set off by the passage of the vibrations emanating from an earthquake in the Aleutian Islands.<sup>2</sup>

*Voyage from Valparaiso to Panama, and thence to New York.* On the 7th of January 1909, I sailed from Valparaiso by the Chilean steamship *Limari* for Panama, with stops at various ports on the intermediate coast. Along this coast as far north as the island of San Gallan near Callao, from time to time one sees from the deck of a passing vessel sea-caves somewhat above the present level of the sea, indicating a modern uplift in relation to sea-level. Above these recent indications of a change of level the embayments of the coast are terraced as at Coquimbo and Ilo to a height of a few hundred feet. Usually above the highest terrace which is somewhat more eroded and creased by ravines than those successively lower, there rises a dissected slope to the edge of the lofty plateau. That these terraces facing the sea indicate changes of level one can hardly doubt. Were they due to differential weathering the upper ones would be as sharply defined as the lower terraces. In this respect the coast is in sharp contrast to much of the region south of Valparaiso. We reached Panama January 26, where our fellow-passenger Colonel Gorgas of the Isthmian Canal Commission showed us many courtesies. On January 27 I sailed by the Royal Mail Steamship *Nile* for New York with a stop at Kingston, Jamaica. This enabled me to spend a day in the examination of the destructive work of the earthquake of January 14, 1907, the effects of which were visible on every hand in the unfortunate city. The *Nile* arrived at New York February 4th, 1909.

<sup>1</sup> The initial Valparaiso shock according to the results obtained at Laibach took place at 0h. 40m. 5s. Cf. Galdino Negri. *Velocidad de propagacion de las Ondas Sísmicas.* Observatorio astronómico de la Universidad nacional de la Plata. Memoria presentada al IV Congreso científico internacional americano celebrado en Buenos Aires del 10 al 25 de Julio de 1910. La Plata, 1911. p. 100.

<sup>2</sup> See in this connection, *Quelques constantes sismiques trouvées par les macro-sismes.* Nota d'Emilio Oddone da Roma. Strassburg, Bureau Central, 1907.

## IV. OUTLINE OF THE GEOLOGY OF SOUTH BRAZIL.

For the understanding of the relations of the Permian glacial deposits of south Brazil it is proper to give a résumé of the geological structure of the country. Passing over the pioneer work of Lieut. Colonel Wilhelm L. von Eschwege, whose writings are lithological rather than geological, the main outlines of this structure are to be found in the publications of Dr. Orville A. Derby and his associates, Dr. J. C. Branner's résumé in his *Geologia elementar*, and in Dr. I. C. White's Report on the coal area. In this résumé the observations of the writer have been allowed to a limited extent to enter into the interpretation of certain features of the region.

The formations which enter into the structure of this part of Brazil may be grouped in the following terranes:— 1. The Pre-Devonian or igneous and metamorphic belt of the coast including the Serra do Mar region, frequently classed as Archean. 2. The Devonian including the sandstone cuesta of the Serra das Furnas and the overlying fossiliferous shales of Ponta Grossa in the state of Paraná. 3. The Permian beds, including conglomerates, tillite beds, as well as sandstones and shales, the latter coal-bearing in the south. 4. The Triassic sandstones and trap sheets; the latter making the escarpment known as the Serra Geral and its topographical equivalents elsewhere. 5. The Tertiary fresh-water deposits of the upland and possibly along the coast. 6. The Recent deposits along the coastal border now slightly elevated.

*The Pre-Devonian Terrane.*—The Pre-Devonian belt is here so-called because it comprises a complex of igneous and metamorphosed sedimentary rocks unconformably overlain by the westward dipping Devonian sandstones and shales of the upland, as yet the oldest known fossiliferous group in the region. The use of the term Archean or Pre-Cambrian for this complex seems at present inadvisable because of the possibility that certain of the metamorphosed clastic members of the series may be of Lower Silurian (Ordovician) or Cambrian age analogous in their structural relations to those of these ages in the metamorphic belt of the Piedmont terrane of the Atlantic slope of North America.

In the latitude of Rio de Janeiro this belt of complex rocks includes the elevations known as the Serra do Mar and an inner line of mountainous relief known as the Serra da Mantiqueira. Gneiss of undetermined origin appears to be the most ancient member of the region

and may be fairly presumed to be of Pre-Cambrian age. In the coastal border gneissoid granites with well-developed augen-structure abound. This rock is nowhere better shown than about Rio de Janeiro, as in the Pão de Assucar at the entrance to the harbor. Apparently of later date than the granite-gneisses are intrusions of phonolite and tinguaitite which occur in the form of stocks, while more basic dikes are not wanting.

In eastern São Paulo there is an evidently infolded belt of slates and limestone, seemingly the newest member of the metamorphosed series. The distribution of this formation has not been shown on geological maps. In southeastern Santa Catharina the belt between the Permian border and the coast appears to be entirely granitic, though north of this district quartz-schists are involved in the complex as in the vicinity of Itajahy.

North and south of the Permian-Triassic basin of south Brazil these Pre-Devonian rocks have a vast extension, stretching far into the interior in the state of Minas Geraes and forming the greater part of Uruguay. In the region south of Rio de Janeiro it is evident from the relations of this series to the overlying Devonian beds that one or more periods of deposition, mountain-building, and igneous intrusion preceded the deep erosion of the deformed mass as the prelude to the incursion of the Devonian sea. The once eastward extension of this deformed and eroded Pre-Devonian terrane into what is now the basin of the Atlantic Ocean has no assignable limits. The basal beds of the Devonian rest on a westward dipping now slightly warped surface of these older rocks in a manner to show that the sea crept in over a region of little or no relief but how far this peneplaned surface extended to the eastward there are no definite facts to show.

*The Devonian Terrane.*—The Devonian of south Brazil occupies a narrow belt of outcrop along the eastern margin of the Permian area, disappearing on the north in São Paulo and on the south in Paraná. As strata of Devonian age reappear far to the northwest at Cuyubá in Matto Grosso, the Devonian is thought to extend beneath the Permian and Trias over a vast area. It is agreed that the Devonian of South Brazil includes at its base the thick, light-colored sandstones which form the Serrinha and the Serra das Furnas. This formation is overlain by fossiliferous shales of Mid-Devonian age. The Devonian shales are intruded by numerous dikes and sills of diabase whose outcrops may be seen in the vicinity of Ponta Grossa. Their date of intrusion is probably Triassic. The absence of the Devonian

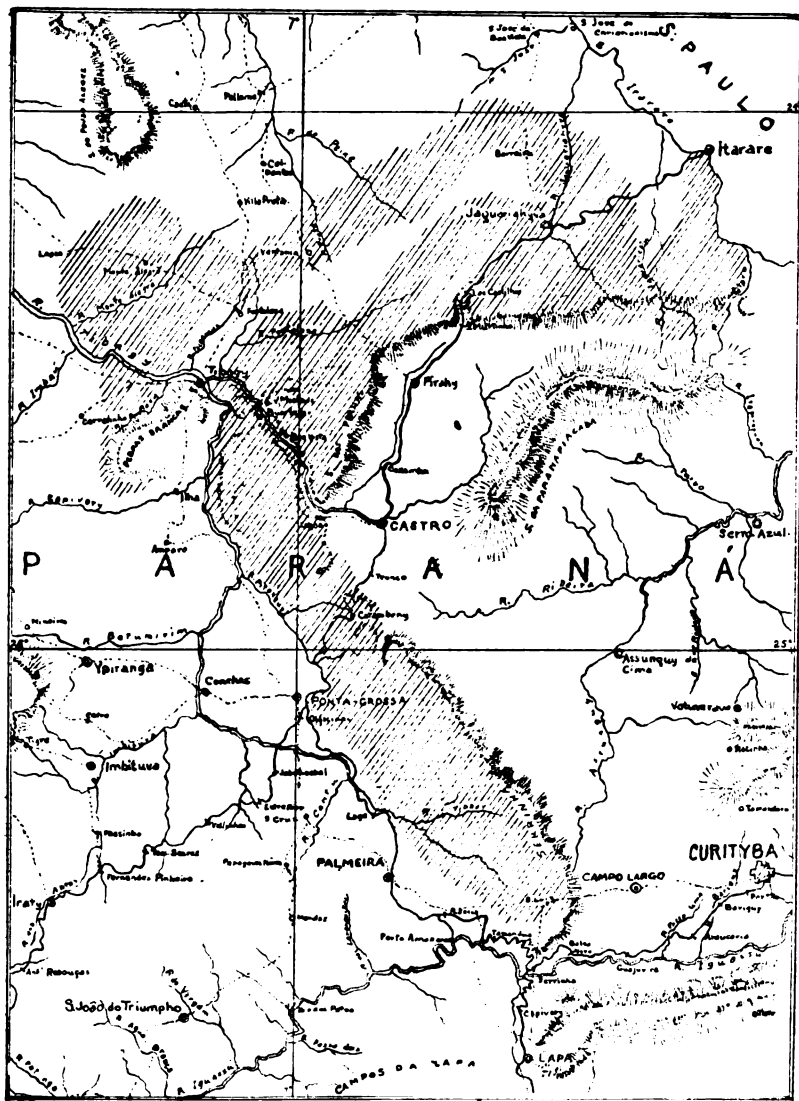


FIG. 7.— Map of the Devonian area in Paraná. The lined area is Devonian; that on the west is Permián; that on the east is the Pre-Devonian metamorphic and granitic terrain. (Published by permission of the Director of the Geological and Mineralogical Service of Brazil).

north and south of the present line of outcrop where the Permian rests upon the Pre-Devonian terrane is evidently due to erosion of the beds in Upper Devonian or Carboniferous times.

That the unfossiliferous sandstones referred to the Lower Devonian represent the shoreward facies of marine sediments is clear and it is possible that the upper part of the beds may represent shore deposits laid down simultaneously with the lower off-shore portion of the fossiliferous shales known to be of Mid-Devonian age. The thickness



FIG. 8.— Sandstone escarpment looking northeast from Lago, Paraná.

of the outcrop of shales is however such as to indicate that they originally extended much to the eastward of the present underlying eastern limit of the sandstone just as the peneplaned surface on which the terrane rests evidently extended to the eastward of its existing traces.

The inference above stated that the Devonian shore in this region lay to the eastward is not only suggested by the westward existing dip of the beds, which attitude might be explained by a rotational tilt from an original eastward dip, but the assumption is in consonance with the basin-like form of the entire geological province of south Brazil. In Triassic times over a vast area non-marine sediments were poured on to this tract from outlying areas of land. In the preceding Permian both marine and non-marine sediments accumulated in the same or nearly the same area; and on the eastern border of the outcrop of these sediments, as will be shown later, there is evidence of the derivation of materials from an area of erosion on the east. The Carboniferous period was here one evidently of uplift or withdrawal of the sea and erosion under the atmosphere, a fact of little import on the attitude of the Devonian stratigraphic plane other than to indicate the probable proximity of land in this region in the later Devonian.

*The Permian Terrane.*— It now seems most likely that the strata referred to the Carboniferous in the earlier reports on this district are of Permian age. The fossil plants and few reptilian remains found

above the base of the series are without doubt referable to the Permian. The Permian strata are known along a narrow belt from southern Minas Geraes southward through the states of São Paulo and Santa Catharina; they extend into Rio Grande do Sul where the beds turn westward on the southern border of the basin-shaped area of late Palaeozoic and early Mesozoic sediments which form the central geological province of South America. Except where the Devonian beds intervene these strata rest with marked unconformity upon the Pre-Devonian rocks. According to Dr. Derby<sup>1</sup> the Permian consists of the following beds:—

|                      |                                       |                                                                |
|----------------------|---------------------------------------|----------------------------------------------------------------|
| Rocinha limestones.  | 3 meters.                             | Stereosternum bed.                                             |
| Estrada Nova shales. | 150 meters.                           | Gray, mottled shales with flints; known in Santa Catharina.    |
| Iraty shales.        | 70 meters.                            | Black shales with Mesosaurus.                                  |
| Palermo shales.      | 90 meters.                            | With fossil wood.                                              |
| Coal measures.       | 150 meters.                           | Sandstones and shales with 2 beds of coal. Glossopteris flora. |
| Tillite beds.        |                                       |                                                                |
| Basal beds.          | Sandstones with boulders and pebbles. |                                                                |

Dr. I. C. White in his admirable Report<sup>2</sup> on the coal fields of south Brazil groups the Permian beds in the following section:—

|                    |                                                                   |      |
|--------------------|-------------------------------------------------------------------|------|
| Passa Dois series. | Rocinha limestone.                                                | 3 M. |
| 223 meters         | Estrada Nova shales with chert                                    | 150  |
|                    | Iraty black shale (with Mesosaurus) <sup>3</sup>                  | 70   |
| Tuberão series.    | Palermo shales                                                    | 90   |
| 180 meters         | Rio Bonito sandstones and shales with coal and Glossopteris flora | 158  |
|                    | Orleans conglomerate                                              | 5    |
|                    | Yellow sandstones and shales to granite floor                     | 27   |

Total thickness 403 meters or 1,322 feet.

Dr. White appears to regard the various formations of the Permian as more or less persistently parallel throughout São Paulo, Paraná,

<sup>1</sup> Verbally communicated at Ponta Grossa in 1908.

<sup>2</sup> Dr. I. C. White, Relatório final apresentado a S. Ex. o Sr. Dr. Lauro Severiano Müller. Comissão de Estudos das Minas de Carvão de Pedra do Brasil. Rio de Janeiro, 1908, p. 33.

<sup>3</sup> Dr. White includes Stereosternum in this bed; but this is an error: it is found in the Rocinha limestone.

and Santa Catharina. The best defined horizon is described as that of the Estrada nova shales with flint concretions. So far as I could ascertain in 1908 the *Glossopteris* flora and beds of coal are only well known on the south in Santa Catharina while deposits with fossil trees are found on the north in São Paulo. The typical tillite beds are at present best known and apparently most extensively developed in the state of Paraná. On the north in São Paulo only scattered stones occur in the beds. On the south in the Tuberão Valley no tillite beds are found but waterworn conglomerates occur. Farther south and west in Rio Grande do Sul some of the reports mention boulders near the base of the section which may be presumed to indicate Permian ice-action, but tillite has not been described from there. Heretofore the Permian has shown only non-marine organic remains but the discovery of a sparse marine fauna in black shales near Rio Negro intercalated in the boulder-bearing beds demonstrates the at least temporary invasion of the district by the Permian sea. The sections traversed by the writer in São Paulo between Itaicy and Piracicaba, in Paraná between Ponta Grossa and Conchas on the Tibagy, between Lapa and the base of the Serra do Espigão, and in southeastern Santa Catharina along the Tuberão Valley, seem to bear out the above statement as to considerable variation in the character of the sediments from point to point in the lower portion of the series. The following letter shows the progress of the geological survey up to 1912.

Ponta Grossa, 13 de Dezembro de 1911.

Meo caro Dr. Woodworth.

Saude.

....Estou aqui proseguindo os meus trabalhos e como sei que as suas observações no Brasil ainda não estão publicadas aproveito esta para lhe dar algumas indicações sobre a idade dos conglomeratos glaciaes.

A primeira vez que encontrei camadas com fosseis marinhas em conglomeratos glaciaes foi quando eu estava executando a sondagem do Passinho a 12 km. ao sul de Imbituvo. Estas camadas foram encontradas a partir de 120 metros de profundidade; tinham 45 metros de espessura e nellas achamos uma pequena lingula, escamas de peixes, e restos indeterminados de brachiopodos e lamellibranchios. A partir de 160 metros de profundidade a sondagem atravessou até 395 metros exclusivamente camadas argilosas, sem estratificação, com pequenos seixos, e algunos boulders de granito. Em 1908, na sua companhia descobri a camada fossilifera do Rio Negro. E' um schisto negro, ardoriano, com Lingulas, Discina, peixes e restos de esponjas. Em Outubro deste anno consequi identificar as camadas da sondagem do Passinho. Ellas apparecem no grotão leste de T. Soares, 45 metros abaixo do arenito

amarelo com seixos que ali contêm uma delgada camada de plantas fósseis. A secção é a seguinte:

|                                                                                                                                                                        |             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Arenito amarelo com delgado leito de carvão . . . . .                                                                                                                  | 50. metros. |
| Argilla negra com abundantes restos de insectos . . . . .                                                                                                              | 0.60        |
| Schisto cinzento com rica flora de <i>Glossopteris</i> . . . . .                                                                                                       | 5.0         |
| Schisto cinzento um tanto ardoriano contendo <i>Lingula</i> ,<br>Discina, escamas de peixes, azas de insectos, Chonetes em abundancia, e outros brachiopodos . . . . . | 40.         |
| Camada argilosa com seixos e boulders até o rio das Almas . . . . .                                                                                                    | 60.         |

.... Parece-me não haver duvida de que o conglomerate é Carbonifero medio ao Permiano. Os insectos apparecem não só nas camadas marinhas como as que se acham logo abaixo do carvão.

Esta vista modificada poderá figurar em seu relatorio.

Abraços, o amigo admirador,

Euzebio Paulo de Oliveira.

(Translation by J. B. Woodworth).

Ponta Grossa, 13th December, 1911.

My dear Mr. Woodworth,

Greeting:

..... I am here prosecuting my labors and as it may be that your observations on Brazil have not yet been published I avail myself of this opportunity to give you some data upon the age of the glacial conglomerates.

The first time that I found beds with marine fossils in the glacial conglomerates was when I was executing the boring at Passinho 12 kms. south of Imbituvo. These beds were encountered on going below a depth of 120 meters: they were 45 meters thick and in them we found a small *Lingula*, scales of fishes, and remains of undetermined brachiopods and lamellibranchs. Below 160 meters in depth the boring traversed down to 395 meters exclusively shaly beds, without stratification, with pebbles and some boulders of granite. In 1908, in your company, I discovered the fossiliferous bed on the Rio Negro. It is a black, combustible shale, with *Lingula*, *Discina*, fishes and remains of sponges. In October of this year I found the equivalent of the beds of the boring at Passinho. They appear in the ravine east of T. Soares, 45 meters below the yellow sandstones, with pebbles, that here contain a thin bed of fossil plants. The section is as follows:—

|                                                       |            |
|-------------------------------------------------------|------------|
| Sandstone, yellow, with thin layer of coal,           | 50. meters |
| Shale, black, with abundant remains of insects.       | 0.60       |
| Shale, ashy, with rich flora of <i>Glossopteris</i> . | 5.00       |

do do somewhat burnable, containing *Lingula*, *Discina*, scales of fishes, wings of insects, Chonetes in abundance, and other brachiopods. 40.00

Argillaceous bed with pebbles and boulders down to the river das Almas 60.00

.... It appears to me not to be doubted that the conglomerate is Carboniferous intermediate to the Permian. The insects appear not only in the marine beds but in those which occur immediately below the coal.

This view modified may figure in your report.

Cordially yours,

Euzebio Paulo de Oliveira.

Dr. Derby, in 1888, in a letter to Waagen, which was published by that geologist (Derby, 1888) announced the occurrence in this series of erratics and likened the deposits to those of the glacial beds of the

Permian in India and Australia, a view which every subsequent geologist who has attentively examined the evidence in the field has concurred in. (I. C. White, 1908).

The identification by Mr. David White (in I. C. White, 1908, p. 281, etc.) of the *Glossopteris* flora in the shales of the coal measures of Santa Catharina has completed the evidence as to the Permian age of those beds. In the correlation made with the Permian of India and elsewhere by Mr. White, there is a satisfactory agreement. In south Brazil as elsewhere the tillite beds occupy a position inferior to the main occurrences of the flora.

Though mainly of non-marine origin, the Permian sandstones and shales as well as the glacial beds were deposited at or near sea-level. Further consideration of the geographical conditions of the period is deferred to the sections dealing with the conditions of Permian glaciation.

*The Triassic Terrane.*—Surmounting the Permian strata of south Brazil there comes a group of mainly red beds with great sheets of trap forming its highest members. The basal beds of this series have afforded the remains of the Triassic reptile *Scaphonyx* and of fossil wood. The series is apparently in unconformable relation to the underlying Permian. According to Dr. Derby the beds on their northern limits overlap the Permian and rest upon the Pre-Devonian terrane. The series in most respects recalls the Newark group of Upper Triassic age in eastern North America.

According to Dr. White's report (1908, p. 33) the Trias is comprised of the following members:—

|                   |                                                                          |        |
|-------------------|--------------------------------------------------------------------------|--------|
| São Bento series. | Serra Geral eruptives . . . . .                                          | 600 M. |
| 900 meters        | São Bento sandstones, red, gray, and<br>cream colored beds . . . . .     | 200    |
|                   | Rio do Rasto red beds with <i>Scaphonyx</i><br>and fossil wood . . . . . | 100    |

The reports are not always explicit as to the nature of the trap sheets. Though apparently generally regarded as lava-flows Dr. White speaks of examples in southern Santa Catharina and Rio Grande do Sul in terms indicating the existence of thick sills. In this region, he also describes the underlying beds as intruded by great irregular dikes as if they were feeders to some of the overlying trappean masses. In general the Triassic area forms in south Brazil an elevated plateau attaining elevations of 4,000 feet faced where it overlooks the Permian tract by an escarpment crowned with sheets of basalt. The eastern

border of the Triassic formation thus constituted is deeply notched by the greater rivers, such as the Iguassú. The escarpments lying like great loops on the eastern limits of the formation between these river valleys receive various names such as the Serra Geral, the Serra da Esperança, etc. Siemiradzki in a section reproduced by Suess gives a somewhat different interpretation to the trap mass of the Serra da Esperança, but the section of the same field credited to Derby is in harmony with the structure here described as is also the section traversed by the writer between Rio Negro and Lages in Santa Catharina. Further consideration of the Triassic rocks and their bearing on the climatic conditions succeeding the Permian glacial epoch are reserved for a following chapter.

*The Tertiary Deposits.*—Whether or no the Cretaceous deposits covering the border of the continent south of the Amazon have representatives now in some of the sands and clays of the coastal border south of Rio de Janeiro, there are rather recondite reasons for believing that such deposits may once have flanked the coastal slope of the Serra do Mar province; if so they were not long after their deposition worn away. On the upland or planalto, to use the Brazilian name of the plateau region, no known deposits occur between the Trias and certain sediments in São Paulo which from their fossil fishes are shown to be of fresh-water origin and Tertiary in age. These deposits are most extensively developed in the valley of the Parahyba between the Serra da Mantiqueira and the Serra do Mar and in a smaller tract underlying the city of São Paulo. In these cases, the beds occupy not well understood depressions in the Pre-Devonian terrane. In what follows on the topography of the plateau, the occurrence of these non-marine deposits will be advanced as evidence of a change of attitude of the region in late Tertiary times.

*General Structure of the South Brazilian Permian Area.* It remains to describe the general structure of the region embracing the states from São Paulo southward to Rio Grande do Sul. A glance at the geological sketch map, Plate 15, shows that this region has been warped in Post-Triassic times. A broad synclinal structure with its axis in an east and west direction occupies southern Santa Catharina and northern Rio Grande do Sul, causing the Permian and Triassic in turn to approach the Atlantic coast; and, because of the depression of the beds towards the synclinal axis, they attain sea-level and in the case of the Permian descend below that level. On the north of this structure a complementary anticlinal axis is less well defined in central eastern Paraná. Its position is marked out by the arcuate trend of

the Devonian sandstone cuesta in the Serra das Furnas and by the Serra da Paranapiacaba.

That this gentle broad warping of the Post-Devonian strata is of Post-Permian date is shown by the sinuous trend of the outcrops of the Permian terrane. That it is Post-Triassic is also indicated by the down bending of the trappean sheets in the syncline on the south. Precise evidence of a local nature is apparently lacking to demonstrate how long after the completion of the local Triassic section the deformation was produced. The dislocation of the Triassic Newark beds of eastern North America in presumably early Jurassic time would lead us to admit that the deformation of south Brazil may have taken place at this time. For topographical reasons set forth in the account of the physiography of this region (p. 99) it seems that this type of deformation took place in Pre-Cretaceous times. A Jurassic date for the deformation thus appears the most probable one.

*Summary of Geological History of the south Brazilian Plateau.*—From this brief account of the geology of the south Brazilian plateau it appears that, long prior to the Devonian period, the region passed through a series of changes registered in the occurrence of igneous and metamorphosed sedimentary rocks as yet little understood. At least one series of sediments now slates and limestones involved in the complex may be the equivalents of the Ordovician or Cambrian strata but fossils are wanting to prove the age of these beds. The basal Devonian sandstones resting on the eroded edges of these metamorphosed and intrusive rocks can only be interpreted as evidence of land conditions in the epoch preceding the Devonian and hence in the Silurian (Upper Silurian of Murchison). The Devonian sea transgressed the area and continued depositing sediments through the middle of that period. Whether deposition took place in the Upper Devonian is not now clear. The Carboniferous period was so far as the records go one of land denudation in which most of the Devonian was swept away. The extent of this denudation is such as to render it probable that higher Devonian beds originally overlay the Middle Devonian shales of Paraná.

True Carboniferous deposits appear to be wanting in the area, such strata as may have been referred to this epoch belong rather to the basal Permian.

The Permian is characterised by a series of mainly non-marine formations laid down at or near sea-level with locally well-developed beds of tillite indicative of a glacial period. Elements of the Glossopteris flora have been found in Santa Catharina in shales which carry

thin beds of coal. The lower members of the Permian section display no marked persistence north and south but towards the top of the section more uniform conditions of deposition appear to have prevailed. The horizon of the Iraty black shales near the top appears to be fairly continuous.

The so-called Trias characterised by red beds and contemporaneous basaltic outflows and intrusions marked a great change of geography and climate. Arid conditions succeeded to the moist climate of the Permian but stream action appears to be demanded for the deposition of the thick sandstone beds devoid of marine fossils. Presumably at the close of the Triassic episode of deposition and at some stage in the Jurassic period the region underwent gentle warping producing the present structure of the plateau.

The Jurassic and Cretaceous periods are in this region without existing remnants of deposits. If the elevated Cretaceous marine beds of the north originally extended so far south, it is to be presumed that they were preceded by an epoch of baselevelling and in the following Tertiary time by the uplift of the district in such a manner as to give rise to the Serra do Mar slope to the sea-floor. Erosion of the plateau surface and of the short slope to the sea has worked out in accordance with the specific resistances of the several terranes the existing topography of the region, with a late Tertiary interruption of the cycle of erosion indicated by small basins of non-marine Tertiary beds in São Paulo. Over this surface a mantle of unconsolidated materials produced by weathering with more or less transportation has accumulated during Pleistocene and Recent times.

The annexed cross-section of south Brazil, after Derby, exhibits the essential features of the structure of the plateau in the latitudes where the Devonian strata occur.



FIG. 9.— Geological cross section of south Brazil (after Derby).

For a bibliography of Brazilian geology, the catalogue of publications prepared by Prof. J. C. Branner (1909) should be consulted.

## V. PERMIAN GLACIAL DEPOSITS OF SOUTH BRAZIL.

"In the next great section of the earth's crust, the Permian period, we have an almost world-wide extension of glacial waste \* \* \* Even in the Southern Hemisphere we have what seems to be conclusive proof that the glaciers during this age operated in regions nearer the equator than they did during the last glacial period."

SHALER in *Shaler and Davis. Glaciers*, Boston: 1881, p. 96.

"Evidence is slowly accumulating which serves to show that glacial periods of greater or less importance have been of frequent occurrence at all stages in the history of the earth of which we have a distinct record."

N. S. SHALER. *Outlines of the Earth's History*, New York: 1899, p. 247.

The foregoing statements concerning the boulder-bearing Permian beds of south Brazil show the state of the inquiry concerning the origin of these deposits as late as 1908. Dr. Derby, Professor Branner, and Dr. I. C. White were essentially in agreement in regarding as highly probable the glacial origin of the boulders, but striated rock surfaces either of the bed rock or as transported erratics were wanting.

The boulder-bearing beds of the Permian in south Brazil are far from presenting a persistent parallelism of strata from point to point along their outcrop. In the state of São Paulo the typical tillite is seemingly wanting except near the southern border, the evidence of ice-action being limited largely to argillaceous sandstones carrying occasional stones and boulders. The typical tillites crop out on the northern border of the state of Paraná and are exposed at what appears to be more than one horizon as far south as Santa Catharina. In eastern Santa Catharina in the section along the Rio Tuberão there are no surface exposures of tillite, but waterworn conglomerates occur at a low horizon in the section apparently representing as at Ponta Grossa in Paraná the glacial episode.

The following account of the sections studied by myself begins with the beds on the north in the state of São Paulo, and includes the following sections: —

- a. The section from Itaicy to Piracicaba in São Paulo.
- b. The section on the Rio Jaguaricatu in northern Paraná.
- c. The section from Ponta Grossa to Conchas, Paraná.
- d. Exposures between Ponta Grossa and Serrinha, Paraná.
- e. The section from Serrinha via Lapa to Rio Negro, Paraná.
- f. The Orleans-Minas section in the Tuberão Valley, Sta. Catharina.

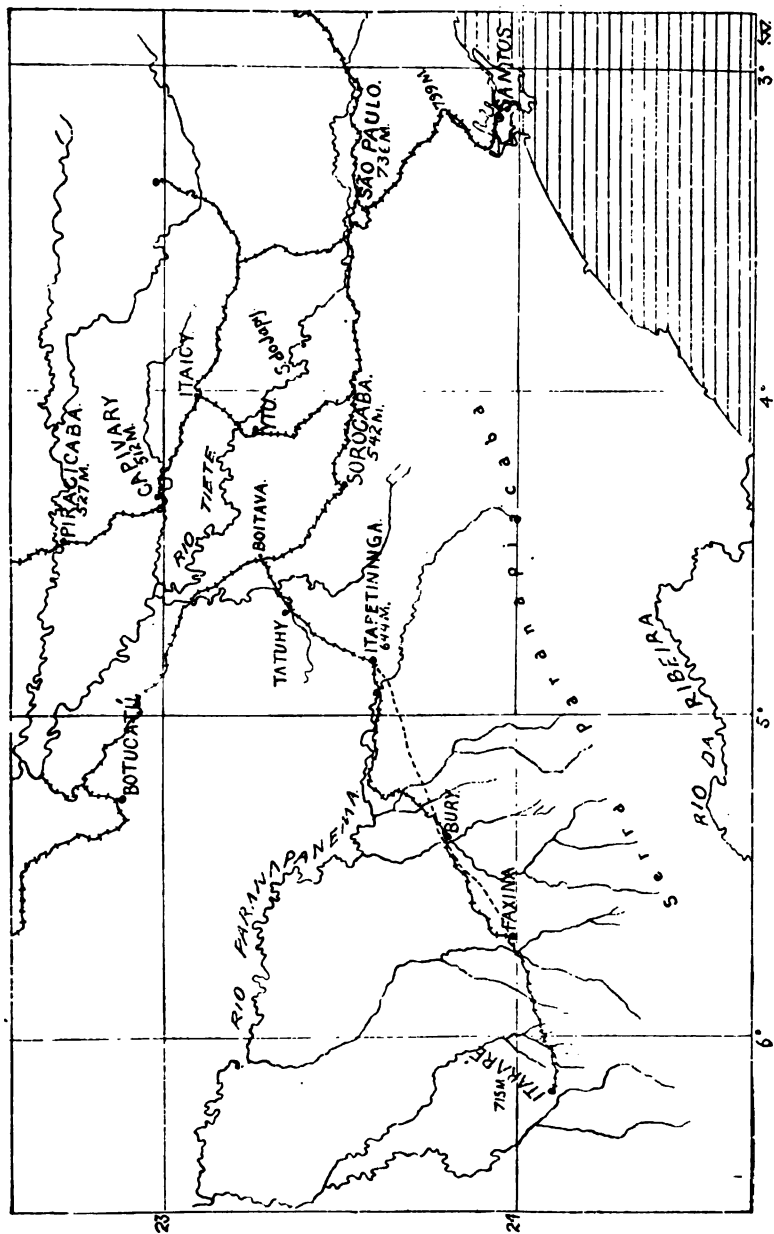


Fig. 10.—Sketch map of southeastern part of state of São Paulo.

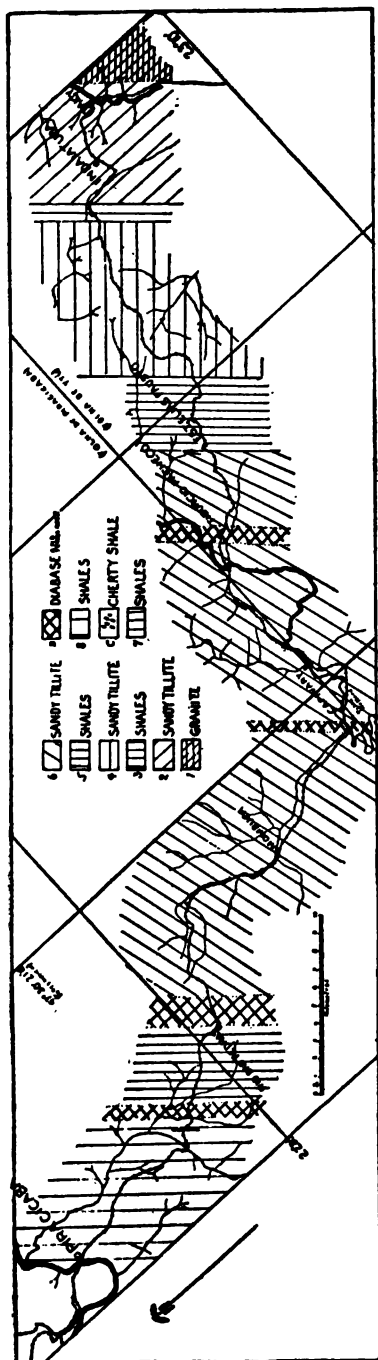


FIG. 11.—Sketch map of Permian along railway line between Itaicy and Piracicaba, São Paulo. The projection of the strata beyond the line of route is subject to correction for topographic relief.

The section from Itaicy to Piracicaba:—A reconnaissance was made of the section from the granite base at Itaicy along the railway upwards in the series to Piracicaba. The following rough notes serve to bring out the general character of the strata below the reptile-bearing Permian horizon at the latter place and have been made the basis of the accompanying section and sketch map. The station numbers are those of the kilometer posts along the curving and locally recurved line of the railway. Notes and posts are given in the order in which they came. Itaicy has an altitude of 1,200 M. (1,870 ft.) according to local contour of the map.

151. Granite boulders; in place (?).
153. On sediments. No boulders noted. One stone in yellowish topping. Cut with pebbles; shale over sandstone.
154. .... Reddish massive sandy shale (now clay). Pebbly sandstone; no striae seen on pebbles.
155. ....

156. near  
Indaiatuba (Indaia, wild fruit; tuba, many).
157. Canga (limonitic crusts).  
Bridge.
158. ....  
Reddish sandstone.
159. ....  
Shales.  
Crew house. Boulder on surface.  
Massive checkered clays (shales).  
Surface covered with cobbles.
160. ....  
Small overturned fold south side of track in strongly folded  
shales. Beds dip N. W. Dark shale bed.
161. ....  
Cut showing yellow sandstones above last.
162. Cut, with cobblestones in shales.  
Cut with sandstones.  
do.
163. ....  
Deep cut, sandstones without pebbles.
164. ....  
Boulder on surface.
165. Red cut.
166. Long cut; red sandstones without pebbles.
- 167 to 169; no exposures.  
Red beds with pebbles.
- 170-171. Folded yellow tillite (?) bed.  
Shaly sands now clayey.
172. ....  
Red shallow cut.
173. do.  
do.
174. ....  
Bouldery shales; 2 ft. boulder of quartzite. Also diabase sill?  
Small fault running east-west; downthrown to west.  
Black band bed. Carbon or manganese?
175. ....  
Shale.
176. ....  
Black shale.

- 177 to 178; no exposures.  
Boulder near Elias Fausto; ca. 2 ft. size.  
Shales.
179. ....  
Tillite or sandstone; boulders loose on surface.
180. Long cut in sandstone.  
Yellow clayey sandstone to
181. ....
182. ....  
Cut in diabase sill.  
Tillite sand on top of diabase.
183. do.
184. ....  
Diabase sill to Tuburcio Pacheco Station.  
Yellow beds with stones.
185. Tillite?
186. Rio Capivary.  
Dark shales with embedded stones.
187. ....  
Tillite section, in which I find large angular piece with faint striae; rock a compact white sandstone; like the bed under the Jaguaricatu beds.  
Waterworn pebbles in a layer overlaid by reddish sandstone but these beds are possibly Post-Palaeozoic. S. E. of Faz. Barreiro.
188. ....  
One or two boulders seen on surface.
189. ....  
Black shale; greenish black, containing in cut at least one granite boulder 15 to 18 inches (38 to 45 cm.) long; continue to cross-roads; there overlying
190. Sandstones.  
Yellow fine sandstones (loessite?)
191. ....  
Similar to last; faulted and disturbed; small overthrust of sandy loessite upon shales.
193. ....  
Massive beds of sandstone.  
Rio Capiavary near to
- 194.
195. Near to Capivary Station.
196. ....

- Loessite with boulder; sandstones with small vertical fault; downthrow to east.
- 197; Good cut with two small overthrust faults; overthrust eastward. Yellowish sandy shale. Tillite; fine grained.
198. ....
199. Sugar factory at Villa Rafford.  
In cut beyond station, tillite with boulder of conglomerate (Plate 20). Pebbles in boulder mainly quartzite.
200. ....  
Trap near to
201. ....,  
Trap.  
Tillite.
202. ....  
Sandstones.
203. Cut.  
Boulders and stones in sandy beds.  
Shales; somewhat crumpled.  
Dark shales to
204. ....  
Sandstones.  
Shales; with concretions (?).
205. ....  
Tillite, with stones.  
Long side cut here with sandstones like moulding sands; containing boulders of granite and quartzite.
206. Till-like sandstone.  
Red do.  
Beds with pebbles and small blocks.
207. ....  
Tillite? without pebbles.  
Beds of characteristic yellow, and with bale structure; stones rare and small. Beds flat, to near
208. ....  
Same as last.  
Chert pebbles appear in surface deposit  
Pebbly sandstones in cut.
209. ....  
Sandstones in long cut.
210. do.

Same to Mombuca Station.

- 211. ....  
Shaly bed.  
Pebbly sandstone (tillite?) near
- 212. ....  
do.  
do.
- 213. ....  
Two cuts of same.
- 204. do., in good cut. No stones seen.
- 215. Glacial sandstones.
- 216. do. fine grained.  
Fine mealy sandstones.  
do.
- 217. do.  
Steep dip locally to northeast?
- 218. Shales; thin?  
Red sandstones over last.  
Boulders on surface.  
Purple shales.  
Boulders on surface.  
Red cut. Trap?
- 219. ....  
Brownish red rock in cut; trap.
- 220. do.
- 221. Cut in sands red to brown in color.  
*Terra roza*; deep cut.
- 222. do.  
Trap near
- 223. *Terra roza* cut.
- 224. do.  
Sandstones.
- 225. ....  
Stratified beds, glacial sandstones and shales.  
Rio das Pedras Station.
- 226. ....  
Purplish to reddish alternating sandy layers in cut.  
Shales with sand band.
- 227. Shales.  
do. greyish.  
do. dark colored.

228. ....  
do.  
d.s. with thin sandstone bands.
229. ....  
do. purple.  
Sandstones?
230. ....  
Red cut; bright red; *terra roxa?*
231. ....  
do.  
Shales, purple, under red bed.  
Cherty layer, vesicular, from 1 to 1.5 inches thick; in shales near
232. ....  
Red bed.
233. do.
234. do. *terra roxa?* mixed with sand?
235. do.
236. do. near  
Purple shale (diabase sill above?).
- 237-238.  
Red cut.  
Chert beds.  
Stratified purple shales; dip northwest.
239. ....  
Sandstones and purple shales, thick, interlaminated.
- 240-241.  
Piracicaba Station.

Without deep borings it is hardly possible to obtain an accurate measurement of the thickness of the strata in this section from Itaicy to Piracicaba. Any estimate is increased a slight amount by the small overthrust faults, for which a deduction should be made, though in round numbers this is possibly a negligible quantity. There is also the question of the uniformity of the dip of the beds. The small contortions associated with the little faults demonstrate the existence of some Post-Permian disturbance of the beds, mainly an eastward overthrust. From kilometer post 189 to the cross-road between that post and 190 kilometers, there is a bed of greenish black shale which appears to overlie as in a shallow synclinal fold the glacial sandstones on the respectively south-east and north-west of the exposure. This point is 8.5 kilometers north-west down the supposed dip from the

eastern limits of the Capivary sandstone group. If this interpretation of the structure be correct and the shale bed does not dip into the section immediately westward of this exposure, the question is raised whether it is not a southeastern outlier of the shales which certainly overlie the group westward from Rio das Pedras. In this case the sandstone beds northwestward from Elias Fausto to this shale outcrop instead of being 1,400 feet thick would have a thickness not greater than that of the second belt above the base, *i. e.* about 600 feet. This would reduce the total thickness of the section measured from 4,000 ft. to 3,200 feet.

As for the maximum thickness, neglecting the above possible causes of diminution in the estimated thickness, there is the presumption that the sill of diabase which crops out between the 230 and 231 kilometer posts in the form of a bright red *terra roxa* zone represents the trap sheet which forms the falls in the river at Piracicaba. The upper contact of this layer on the southeast is near the 575 M. contour; on the northwest down the dip at the river it is somewhere near 525 M., giving a drop of 50 M. in 7.5 kilometers or thirty-five feet to the mile, which is equivalent to a little more than a dip of  $1^{\circ}$  to the northwest, and since the strata overlying the sill are presumably parallel to the plane of the sill, we have in this part of the section an estimate of the dip. Again the thin bed of shales at and southeast of Elias Fausto Station have a breadth of outcrop of four kilometers (2.48 miles, say 2.5 miles). Their base on the east along the line of the railway is at about the 600 M. line; their top at the northwest at 575 M. giving a fall of the surface of twenty-five M. in four kilometers or eighty-two feet in 2.5 miles, or thirty-two feet to the mile. Assuming the shale bed to be at least ten feet thick, we should have dip of thirty-six feet to the mile, which considering the approximations on which the estimate is based is in close accordance with the estimate of the dip made for the beds immediately southeast from Piracicaba.

On the assumption of continuity of bedding and dip from the base at Itaicy to Piracicaba, a dip of  $1^{\circ}$  would give a minimum thickness of 1,145 M. or 3,700 feet for the total thickness from the base to the *Stereosternum* beds.

Rough calculations of the mainly sandstone group at the base about Imbaibatuba with a breadth of outcrop of 5.76 M. or 4.19 miles gives an estimate of 436 feet for their thickness, with a maximum of 700 when scaled to the maximum estimate.

The succeeding shale bed 153 feet as a minimum, 226 as a maximum.

The second group of sandstones may be estimated as having at the minimum a thickness of 400 feet, a maximum of 600 feet.

The shales at Elias Fausto Station, by the minimum estimate fifteen feet, by the maximum twenty-two.

The succeeding group composed mainly of sandstones including all the beds about Capivary, by the minimum estimate based on the hypothesis of duplication of exposure through gentle folding 600 feet, or by the maximum 1,400 feet.

From the top of these beds to the shales with *Stereosternum* at Piracicaba 700 feet by the minimum, 1,000 feet by the maximum method.

These minimum estimates give a thickness of 2,343 feet, or about 714 meters.

The Bofete-well record in São Paulo cited by Dr. I. C. White gave forty-eight M. for the Iraty Black shale and 837 feet below that group to the bottom of the well.

The accompanying section (Fig. 12) represents the succession of strata between Itaipu and Piracicaba interpreted on the probable solution that the shales east of the Rio das Pedras are in a synclinal outlier of the beds about Piracicaba.

In this section there appears no bed equivalent in lithological character to the boulder tillites of the Jaguaricatu section in northern Paraná. In the section along the line of the railway there are scattered stones and small blocks embedded indifferently in the peculiar sandstones and shales. This indiscriminate distribution of frequently striated stones in beds of sandstone and shale is presumptive evidence of the action of floating ice particularly in the case of the shales. The weathered state of the sandstones in the railway cuts makes precise comparisons with the deep blue tillite beds farther south difficult and unsatisfactory.

So far in this section of the Permian no marine fossils have been found below the *Stereosternum* beds if indeed that horizon be marine. On the contrary, notwithstanding the trunks of trees discovered by Dr. Derby somewhere near the middle of the section, no fossils appear

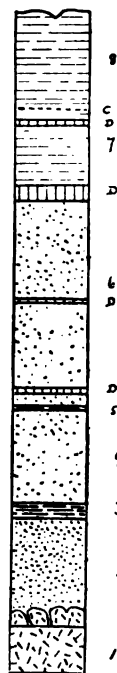


FIG. 12.—Section of Permian from granite floor at Itaipu to Piracicaba. 1. Pre-Devonian granite. 2. Sandy tillite about Imbaetuba. 3. Shales. 4. Sandy tillite. 5. Shales at Estação Elias Fausto. 6. Sandy tillite east and west of Capivary. 7. Shales west of Rio das Pedras. C. Cherty layers. 8. Shales and *Stereosternum* beds about Piracicaba. D. Diabase sills.

to have been found in place; but the tree trunks cannot be far out of position, and the general character of the section points to the sub-aerial accumulation of certain of the sandstones in the manner of outwash plains such as now accumulate in front of glaciers or in similar situations permitting the growth and fall of trees between times of aggradation by débris-laden streams. Only a detailed survey of the region would suffice to determine more definitely the relations to sea-level and the existence of lenses of tillite in the section.

*Tillite Beds on the Rio Jaguaricatu in Paraná.* Sengéns is a station on the newly constructed line of railway from Itararé to Jaguarihyva in northeastern Paraná, on the south bank of the Rio Jaguaricatu. In the railway cuts which were fresh in 1908 good sections of the glacial boulder-clays or tillite were exposed for several kilometers in either direction. The Station is near the 228 kilometer post. The following notes pertain to the exposures along the curving course of the railroad which follows down the right bank of the river towards São Pedro de Itararé. Near post 234 a well-striated sandstone pebble was found dislodged from a sandy conglomerate or tillite at this locality. This pebble is shown in Plate 21 to the left of the hammers. The striated surface is well flattened and the edges battered off. It displays no zigzag striae and may be a fragment of the old glaciated floor. Somewhat farther to the northeast between posts 234 and 235 the boulder-clay type of tillite is well shown, as in Plate 21, there containing small boulders of granite.

Between posts 235 and 236 apparently near the top of the local bed the view shown in Plate 22 was taken. At this point in a fresh railway cut there is exposed an angular slab-like block of a fine grained white sandstone resembling novaculite, nine feet (three meters) long and about twenty-one inches thick, the third dimension not being ascertainable, the largest angular block I myself saw in any section in Brazil. This rock is practically identical, lithologically, with a white sandstone layer which occurs lower in the section at a locality along the railway where a fault brings the beds towards the surface. (Fig. 13).

This fault extends in a northwest direction and the downthrow appears to be towards the west. The sandstone in question is here overlaid by pebble beds. Between these eastern exposures and Sengéns there are coarse sandstones containing at least one pebble bed with a greater proportion of granitic pebbles than are found in the more typical tillite of the district. From this pebble bed I collected three stones carrying faint striae.

West from Sengéns on the north of the Rio Jaguaricatu in one of the deep cuts along the ascending grade striated stones were first found in Brazil. The bed exposed at this locality is a typical tillite, containing large subrounded masses of a whitish rock resembling the

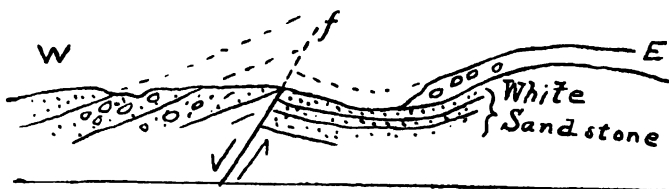


FIG. 13.—Section along the railway showing white novaculitic sandstone bed under tillite bed.

white, fine, silicious sandstone from near the base of the Permian section.

This occurrence of the fine white sandstone in the boulder-beds from São Paulo southward in close association with the preglacial stratum of the same character is strong evidence of the eastern derivation of the erratics.

*Conglomerates at Ponta Grossa:*—Overlying the trap-invaded fossiliferous Devonian shales which underlie the “big point” between



FIG. 14.—Section of Permian conglomerate beds in vicinity of Ponta Grossa, Paraná.

streams on which the city of Ponta Grossa stands, there are to be seen on the northwest of the town near the base of the Permo-Carboniferous series, at least two beds of waterworn conglomerate (Fig. 14) interpolated in a thick sandstone series. These waterworn pebbles present in themselves no evidence of glacial origin or transportation. The lower pebble bed, from four to five feet thick, is made up of subangular to well rounded, waterworn, light-colored sandstone pebbles from .5 inch to 6 inches in diameter. Rarely larger cobble-

stones occur at the top of the bed embedded in the overlying sandstone. No glacial striae or facets were seen on any of the exposed pebbles. Besides the sandstone pebbles, I saw one of micaceous quartzite, a crumpled phyllite, a whitish chert, a red argillaceous sandstone, a decomposed granite with reddish feldspar, a silicious schist, *in toto* a variety of rocks indicating the derivation of at least a small portion of the débris from the Pre-Devonian terrane. The pebbles could hardly have been transported far by water action alone, because the sandstones pebbles are of a sort which do not wear well in any stream journey. I estimate their journey as stream pebbles to have been tens of miles rather than hundreds of miles. The assemblage of these pebbles in a well-stratified bed between layers of a coarse-grained sandstone leaves no doubt of water action. A few feet of sandstone separates this bed from the one above, in which the sandstones pebbles again formed the predominant constituents but were noticeably more rounded than the crystalline pebbles. Dr. I. C. White mentions in his Report a bed of boulders at Ponta Grossa and a deposit containing fossil wood, but I saw none, nor were such deposits known to the Geological Survey staff at the time of my visit.

*Tillite Bed at Conchas:* — Conchas lies on the north side of the Rio Tibagy about four leagues west from Ponta Grossa. On the south



FIG. 15.— Fracture of the tillite bed at Conchas.

(Fig. 15). No striations were seen on the pebbles. The mode of occurrence of the pebbles seems best explained by dropping from floating ice and probably the clay with its sand grains of irregular size originated in the same manner. The rock when exposed to the weather breaks down by a process of checking and the opening of ragged fractures into smaller and smaller blocks so that it is valueless for building stone.

This bed overlies the sandstones with waterworn pebbles at Ponta Grossa, and recalls in its lithological characters the beds on the south of the Rio Jaguaricatu east of Sengéns and also the beds southeast of Rio Negro.

of the village a small quarry was opened some years ago in a grayish somewhat indurated stony clay bed, a boulder-clay phase of the tillite beds. The scattered pebbles consist of silicious rocks and rarely a granitic pebble. The bed fractures with a giant ball structure

Signor Cicero de Campos (1908, p. 3) of the Brazilian Geological Service states that between the port of the Indias and Salto-Maua in Paraná there outcrops a little below the falls on the left bank of the Rio Tibagy a yellow sandstone with enormous blocks of pink porphyry granite and of porphyry. The fall is caused by basalt. Campos refers the strata of the hilltops to the Carboniferous (Permian?).

Near the sixty kilometer post on the railway from Ponta Grossa to Porto da União I noted an exposure of the compact yellowish beds which appear to be the weathered phase of the tillite as at Conchas. A large boulder was also seen in a cut a short distance north of this locality.

*Boulders and Pebble Beds near Palmeira.*—On the divide south of Palmeira yellowish compact beds with blackened joints exhibit a few pebbles north of the 133 km. post. These beds continue in the railway cuts to and somewhat beyond the 130 km. post, then laminated yellow beds come in and a boulder about three feet (1 meter) in diameter appears on the surface west of the track near a house north of 128 km. post, about eleven kms. north of Restinga Secca Station. Large blocks appear in a cut between 122 and 121 km. posts, north of branch road to Amazonas. Beyond 105 km. post, pink pebbly beds are intersected by the railway in the long descent, with tilted pebble bearing beds near 103 km. post. Tilted beds also occur near the ninety-nine km. post, possibly faulted beds. Tamanduá Station is at the ninety-three km. post. Beyond this Station pebbles occur in sandstone at eighty-five km. post; again at eighty-three km. post. At seventy-eight km. post there is a good pebble bed and north of seventy-six kms. gravels appear in a cut.

*The Glacial Conglomerate at Serrinha.*—At Serrinha in the gorge of the Iguassú, where that river has cut deeply into the sandstones at the southern limits of the sandstone cuesta locally known as the Serrinha (little serra), there is a good exposure of beds, the general characters of which are shown in the annexed unmeasured section, (Fig. 16).

There is here east and west of the railroad station an exposure of small pebbled conglomerate rising about twenty-five feet above the level of the track. Quartz pebbles either angular or well rounded occur in this bed, with occasional pebbles of gneiss and possibly granite, together with quadrangular fragments of a now reddish friable sandstone, presumably a rock derived from underlying beds. East of the station between the 69th and 70th kilometer posts, Dr. Euzebio Oliveira found in the conglomerate beneath the sandstones a dis-

tinctly striated pebble, a compound quartz-bearing rock, with one well-rounded side and a surface of more recent fracture. The rounded surface bore striae. The pebbles in this conglomerate are

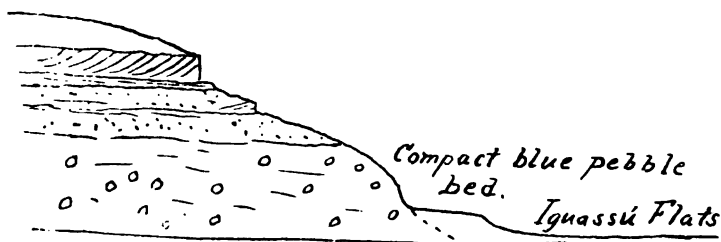


FIG. 16.— Section of the conglomerate and overlying sandstones at Serrinha, Paraná, in the gorge of the Iguassú.

rather closely scattered through a matrix of abundant sandstone of an argillaceous character, suggesting the deposition of the mass by floating ice.

The whitish sandstone overlying this conglomerate is so like that forming the base of the Devonian northward in the Serrinha ridge that the question is raised whether this conglomerate belongs to the Permo-Carboniferous series or to the Devonian. There is no appearance of faulting in the neighboring district which I discerned. The Devonian shales which separate the Devonian sandstone from the basal Permian at Ponta Grossa on the north have at this distance on the south disappeared, and it is possible that the Sandstone has also; the Permian by overlap coming close down to if not in contact with the Pre-Devonian east and north of Serrinha, the local resemblance of the white sandstone to the typical Devonian being assignable to a redeposition of those sandstones. The determination of the Devonian age of the lower beds at Serrinha, should it be made, would introduce another glacial epoch in south Brazil parallel to the case in South Africa. In this report I have preferred to follow the tentative opinion of Dr. Derby that the Serrinha section is Carboniferous (Permian). This view involves at least two advances of the ice in Permian time.

*The Section at Lapa.*—Lapa is a station on the railway south of Serrinha. Along the line of railway southward from Serrinha after surmounting and crossing the sandstones on the south bank of the Iguassú the tillite beds are traversed by the train. Near and north of Pivary the campo surface is strewn with rounded stones. About

a mile east of Lapa the Morro do Monge (Monk's Hill) rises, the most northern of a series of sandstone ridges forming a line of westward facing escarpment, broken down at intervals by cross-valleys presumably of structural origin. This sandstone overlies the tillite beds, and is traceable in these ridges southward to the Rio Negro, south of which it plunges beneath higher beds, in which, as will be shown, isolated boulders are not wanting. At the base of the Morro do Monge sandstone, there is a ferruginously spotted variety, which is locally quarried. At the surface it weathers into fist-sized quartzitic knobs. At the top of the tillite series and beneath this sandstone at the northeast angle of the Morro do Monge, where the road crosses, there is a conglomerate bed about five feet ( $1\frac{1}{2}$  meters) thick with rounded pebbles in a sandy matrix. This is overlain by one foot of sandstone, then by a bed with scattered pebbles and sandstones. In this series I found a polished quartzose pebble with faint striae. Further south along a private road on the west face of the Morro and at about the same horizon as the conglomerate beneath the sandstones I found a loose pebble of striated sandstone, a specimen of doubtful indications. Striated pebbles in this locality at this horizon are rare.

*Between Lapa and Rio Negro.*—South of Lapa the train runs over the yellow weathered surface of the tillite beds. In a cut between kilometer posts 51 and 52 one or more thin sills of diabase appear. South of the Rio Vargem the train ascends one of the sandstone outliers which is deeply dissected by streams. Between the 73rd and 74th kilometer posts on the descent to the valley of the Rio Negro, just under the hard sandstone bed, in a cut a well-defined boulder-bed appears. Some of the rounded masses have a diameter of three feet (1 meter). Occasional cobbles and yellow compact weathered beds at lower levels farther south indicate the continuance of the tillite sands in this direction.

*Localities near Rio Negro:*—About two miles north of the city of Rio Negro on the northwest bank of a stream which falls into the Rio Negro there is a high bluff of laminated shales with a pronounced concretionary structure with very small intersecting joints. These shales carry scattered pebbles at various levels, the pebbles ranging up to six inches in diameter. One of these larger pebbles showed a smoothened sole or side and faint striae. These shales lie above the sandstone at the bridge over the Rio Negro at the city of that name. Some of the pebbles are a hard sandstone; mica schist also occurs. Most of the pebbles were partly rounded, resembling kame and esker pebbles rather than typical stream pebbles. A flattish broken edged piece of sandstone also showed weak striae of glacial character.

Sandy beds with boulders succeed to the shales for a few feet of thickness. Shales come in again above this level, rarely with striated pebbles.



FIG. 17.— Section of Permian shales, boulder-beds, and sandstones at Rio Negro.

The section, at the bridge (Fig. 17) above referred to, displays sandstones at water-level somewhat cross-bedded and carrying scattered pebbles and small blocks. I measured one granitic fragment 16 inches long.

On the south side of the Rio Negro along the road going eastward towards São Bento yellow tillite beds with intercalated dark shales contain many granitic boulders. A cobble eight inches in diameter showed good striation. The boulders range from two to three feet



FIG. 18.— Section of fossiliferous Permian marine shales between boulder-beds near Rio Negro.

in diameter, all in the yellow sandy tillite, with very few small pebbles, arguing for floating ice. A few kilometers along this road eastward from the bridge where a small stream has cut a well-defined valley in its descent to the Rio Negro, Dr. Oliveira found a marine fauna in black shales intercalated between two boulder-beds of the tillite series (Fig. 18). I refer to this bed and its apparent significance elsewhere.

A few kilometers farther east by south along this road a new cut near the small Rio da Vida nova displayed the shales and tillite beds (Plates 23 and 24), at horizons closely corresponding to the beds above

the marine fossiliferous zone. In this locality the shales also carry boulders and stones. That in the view being a boulder of gneiss about twenty inches in the diameter on the exposed section. Below the middle of the part of the bed shown in the plate there is a thin, well-defined layer one and a half inches thick of the yellow material which is called tillite in this paper. The layer consists of sand grains and earth particles with coarse angular grains ranging to the size of very small pebbles, and by its mode of occurrence is strongly suggestive of deposition, like that of the stones included in the shales, by floating ice, probably the manner in which the thicker beds of the same character were laid down in this section. The shales part with a thin splintery fracture subparallel to the bedding.

The overlying tillite bed is composed mainly of fine earthy material with coarse sand grains, and scattered pebbles; some of these latter display glacial striae. Among the types of rock was noticed one example of a coarse-grained diabase. This bed is about eight feet (2.5 meters) thick, and is remarkable for the almost perfect development of the bale structure so characteristic of some varieties of igneous rock. No trace of stratification was detected within the limits of the stratum.

About two Brazilian leagues from Rio Negro and further to the south and east along this same road, the Ribeira das Rutes, a small tributary of the south bank of the Rio Negro, has cut a gorge with a fall at its head in the blue unweathered tillite. This rock contains rather abundant stones in a matrix of clay beset with small subangular fragments of rock and coarse sand grains.

North of the fossil locality above mentioned and lower down along the course of the Rio da Vida Nova the river road intersects a water-worn conglomerate from six inches to two feet thick with pebbles of sandstone and rocks resembling the formation in which it is intercalated. It is overlain and underlain by sandstones of the same yellowish hue as the tillite beds, resembling a solidified loess.

*Section from Rio Negro Southward to the Top of the Series.*—South of Rio Negro and upward in the series, sandstones and shales are crossed by the Lages road as far as the Rio Laurenço, at 1,500 mule paces north of which I saw a large granite block four feet long lying on the outcrop of bluish shales. On the south bank of the Rio Laurenço a thick sandstone formation comes in. Scattered pebbles and a few boulders are seen along the same road farther south towards Sepultura. Beyond this point southward and higher in the section no good evidence of embedded pebbles was seen.

*The Tuberão Valley Section.*—The Permian beds at Orleans and near Minas in the upper valley of the Rio Tuberão are better known than any section of the Palaeozoic north of Rio Grande do Sul. Not only have the coal beds in that hydrographic basin been reported upon at different times by a number of foreign mining engineers but

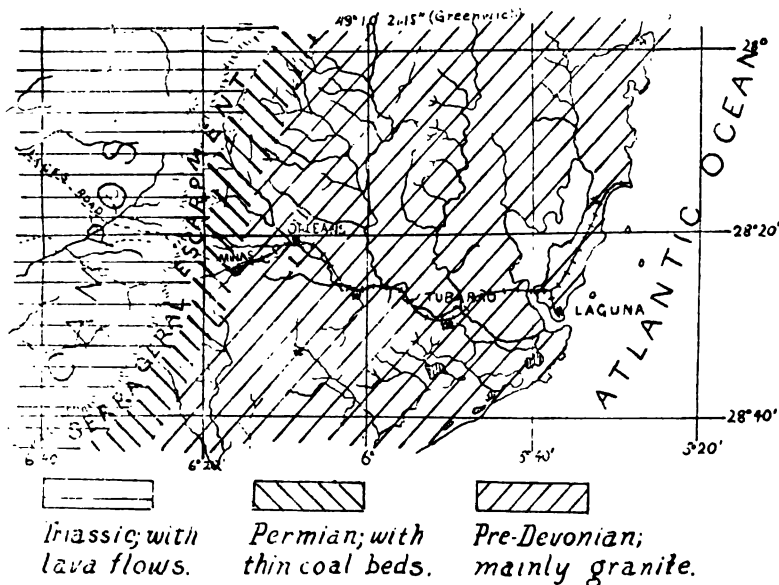


FIG. 19.—Sketch map of the Minas-Orleans district in the Tuberão Valley, Santa Catharina.

the region has been very thoroughly explored by Brazilian geologists and recently the staff of the Coal Commission under the directorship of Dr. I. C. White has made a still more detailed report upon the geological structure and the nature of the strata of this part of the field. According to the terminology of Dr. White's Report this section from the granite basement to the top of the Serra Geral trap plateau comprises the following formations named in descending sequence:—

#### Triassic

- São Bento series
- Serra Geral eruptives
- São Bento sandstone
- Rio do Rasto red beds

## Permian

## Passa dois series

Rocinha limestone

Estrada nova beds

Iraty black shale

## Rio Tuberão series

Rio Bonito beds

Orleans conglomerate

In this report we are concerned mainly with the beds grouped in the above section under the head of the Orleans conglomerate at the base of the Permian section in southeastern Santa Catharina.

Dr. White (1908, p. 51) describes the Orleans conglomerate as follows:—

“Resting upon these lower sandstones and shales often in apparent conformity, we find a coarse conglomerate which is well exposed in the town of Orleans, Santa Catharina, from which locality it has been named. It contains boulders of granite, quartzite, and other hard rocks, some of which are 20 to 25 centimeters in diameter. The same formation is frequently visible along the Rio Tuberão between Minas and 2 kilometers below. The bore hole put down near Minas station began near the top of this rock and passed through the same at a depth of 5.35 meters. In Rio Grande do Sul large granite blocks are frequently found at this horizon, as well as at many points in Paraná and the adjoining region of Santa Catharina, where several localities, near Rio Negro, 10 kilometers from any outcrop of granite, exhibit granite boulders in vast numbers up to 3 meters in diameter, all embedded in a fine and apparently unstratified gray muddy sediment. A very coarse deposit with large rounded boulders of granite, quartzite, sandstone, silicified wood, etc., may also be seen resting unconformably upon Devonian shales at Ponta Grossa, and other localities in that region. This deposit appears to correspond closely to the Dwyka conglomerate of South Africa, and most probably, like it, is of glacial origin, although no scratches were observed upon the boulders in question.” Between the conglomerate and the base there usually intervenes a few meters of sandstones and shales. In the boring at Minas, these beds together with the conglomerate are said to have a thickness of twenty-seven meters. On the road from Lages to Florianopolis farther north the total thickness is from 150 to 160 meters (White, *loc. cit.*, p. 49). At Xarqueadas, in Rio Grande do Sul near the right bank of the Rio Jacuhy a boring was put down in

which a conglomerate 1.80 meters thick is recorded as resting on the granite floor (White, *loc. cit.*, p. 43). Eighteen kilometers southward from Xarqueadas in another boring the Orleans conglomerate is reported with large blocks of granite and with a thickness of 16.16 meters, resting directly on the granite.

In the exposures reported between Florianopolis and Lages and



FIG. 20.— Section of the Minas-Orleans basin.

between Lages and Blumenau in Santa Catharina, there is described among the beds beneath the conglomerate horizon "a very hard fine grained grayish white whetstone grit" in layers eight to twenty centimeters in thickness. These layers it is also stated gave the name Navalha to the village on the Blumenau-Lages road near which locality they were once quarried for whetstones. Similar beds are likewise mentioned in the same report as resting with a few meters thickness on the granite near Suspiro in Rio Grande do Sul and also along the Rio Trombudo where crossed by the Blumenau-Lages road. Attention may here be called to the fine-grained compact white siliceous rock which underlies the boulder-beds on the right hand bank of the Jaguaricatu along the railroad between Sengéns and São Pedro de Itararé in northeastern Paraná described on page 62; fragments of this rock appear to be abundantly distributed in the shales and sandstone of São Paulo often with glacial scratches.

I have little more than details of structure and the conclusions based thereon to add to Dr. White's account of the Permian conglomerates of the Orleans basin. This basin (Fig. 21) is a down-faulted outlier of the Permian area. The boundary fault, on the western margin of the basin, brings the sediments against a basic dike whose shattered condition suggests that the faulting occurred after the intrusion of the dike. A short distance west of this broad dike is a narrow basic dike somewhat faulted within its mass. I observed two nearly vertical slickensided surfaces striking nearly northwest southeast on which the slickensides pitch to the southeast on the eastern fault at angles between twenty-five and thirty degrees and

indicate, by the detailed structure of the surfaces, that the downthrow was on the northeast side in accordance with the structure of the Orleans basin. It is evident therefore that repetitive small faults occasion the base of the Permian section in this district.

The conglomerates are exposed along the river banks below the



FIG. 21.— Section of beds in Orleans basin, south bank of the Rio Tuberão. The rock on west is a broad trap dike.

town and are best shown on the north bank under the railroad track, (Fig. 22). There is here a water laid conglomerate mainly of granite pebbles with a few quartzite and quartz pebbles. The conglomerate is overlain by cross-bedded grits, the cross-bedding dipping to the north and northwest as if deposited by currents of water flowing at least locally in that direction. The pebbles in the conglomerate bed, mostly three inches in diameter, sometimes attain five inches, and are embedded in a paste of granitic detritus. The subrounded shape of the pebbles indicates no distant journey and their lithological character betokens a derivation from the granitic terrane which immediately underlies the local Permian section. (See Plate 25.)

Another exposure of the conglomerate about 90 meters down stream from the preceding exposure presents the cross-section of a north-south ridge of coarse pebbles enveloped in cross-bedded sandstones. In a layer of conglomerate varying from 0 to 60 cm. in thickness the cobbles attain a diameter of 20 cm. The ridge-like deposit, so suggestive of a buried esker, is apparently continued across the river on the south bank of which there is a ridge-like exposure of conglomerate also covered by sandstones. A few yards east of the ridge on the north bank there is exposed a bed with rounded granite pebbles scattered through a sandstone matrix as if dropped by floating ice.



FIG. 22.— Esker-like ridge of conglomerate in lower Permian beds; near Orleans, Sta. Catharina.

All of the strata below the railroad track are essentially devoid of decomposition evidently because of the geologically recent lowering of the bed of the river. While the assemblage of water deposited conglomerates in this section are entirely consistent with neighboring glacial conditions there is no true tillite in the lower part of the section and while the ridge may be an esker the evidence is not conclusive. It is possible to regard the narrow belt of conglomerates as deposited in the channel of an aggrading stream which in its later stages of deposition laid down the cross-bedded enveloping sandstones.

As the Orleans section by no means affords a typical exposure of the tillite beds the name seems inappropriate for the glacial conglomerates



FIG. 23 — Basal boulder in Permian shales, resting on granite, near Minas, Sta. Catharina.

and Dr. White (Woodworth, 1910, p. 779) having kindly coincided in the matter the name *Jaguaricatu* has been substituted for this horizon because of the splendid exposures of tillite along the banks of this river in railway cuts in northeastern Paraná.

In the exposed section of base of the main area at Minas no conglomerates were encountered. A few scattered granite and quartzite pebbles occur in sandy beds but without striae or flattened sides or crushed and snubbed ends indicative of glacial action. About 2.4 kms. below the railway station in a railway cut the basal Permian shales may be seen resting on the Pre-Devonian granites. On this ancient surface reposes a boulder of granite about three feet (1 meter) in diameter covered by the shales. Some small grooves or channels in the granite are filled with a gravelly sandstone. No traces of a glaciated floor were discernible.

It remains to characterize the glacial features of the above described localities as a whole and to draw from the evidence now in hand such conclusions as appear tenable.

There can be no doubt as to the glacial origin of the massive tillite beds in Paraná and their likeness to the tillites of Permian age in India, Australia, and South Africa. The massive aggregation in

northeastern Paraná is highly suggestive of moraines laid down by land ice; but other sections in São Paulo and to the south and west in Paraná are equally clear as to their deposition by floating ice at times at any rate in the sea as the presence of marine fossiliferous marine shales in Paraná plainly show.

More particular problems arising in the study of these glacial deposits are discussed under separate headings.

*The Striated Pebbles.* — So far as present knowledge goes, striated surfaces have not been found on the large boulders and block erratics in south Brazil, but such ice-worn surfaces are frequently met with on pebbles and fragments of rock ranging from the size of a hen's egg to that of a man's head. In almost every exposure of conglomerate whose pebbles fail to display the well-rounded contour of water-wear a few striated pebbles may be found after a few minutes search; yet of these sections I saw none in which all the pebbles and fragments were striated. On the whole the proportion of striated pebbles in the tillite beds is about as large as it is in the granitic till of the glacial deposits of New England, but glaciated stones are certainly not so abundant in any given mass as they are in the stony blue clays of many localities in the Pleistocene deposits of, for instance, portions of the Wisconsin moraines of the state of New York.

The absence or apparent absence of striae from the larger blocks and boulders is quite in keeping with the distribution of striae in the Pleistocene of many districts and has little significance in the arguments for or against glacial action, though in the case of the Brazilian deposits striae were not earlier noted perhaps because attention was given more to the blocks of striking size than to an examination of the worn surfaces of small fragments of transported rock.

*Broken up striated Rock-floors.* — As the glaciation and consequent striation of the indurated terrane over which the ice moves proceeds, the rock-floor particularly at the upstream edges of small declivities in the rock-surface breaks away, so as to produce angular fragments with one flat well-striated surface — that of the original floor. Such pieces of rock may subsequently be striated over all their new fractured surfaces but will for short journeys tend to preserve their features. Thus the striated stone shown in Plate 27, the first striated fragment found in Paraná, presents all the ear-marks on its well worn and striated side of a piece of old rock-floor even to the chatter-marks in the broader and deeper groove; while on the reverse, where there are two intersecting warped surfaces one is slightly scratched, and the other is a much more recent fracture, still of a date anterior to the final embedding of the pebble.

Although no glaciated rock-floor has yet been found in south Brazil, pebbles of the type above described point to the one-time existence of such a rock-floor though it is no longer to be seen. In this particular instance that of a pebble from the tillite beds on the Jaguaricatu the rock is a reddish brown <sup>1</sup> fine compact argillaceous sandstone, with a perceptible clayey odor when breathed on, and carrying minute scales of muscovite.

*Crushed and Blunted Rock Fragments.*—Striated pebbles or rock fragments with or without flattened sides or “soles” are commonly regarded as the most characteristic molar constituents of moraines directly due to glacial action; but there is another type of pebble in ice-laid moraines which is equally peculiar to the process of erosion and transportation; that is the pebble with blunted and snubbed ends with or without striae. This kind of pebble is usually rather elongate and oftener displays its fractured and splintered surface at that extremity which has the smallest cross-section. Such fragments are not uncommon in the glacial drift of North America and I have found them in the tillite of Paraná in the beds along the Rio Jaguaricatu. One example quite characteristic in every feature is illustrated in Plate 27, fig. 3.

The small intersecting surfaces which give rise to the beveled appearance of the subpointed portion of the periphery of this rock fragment are surfaces of fractures produced by the riving off of spalls of the rock through pressure applied at points along the major perimeter of the pebble. In the case of this pebble, there are three such larger fracture surfaces and each of the later fractures was followed by a repetition of the pressure at approximately the same point so as to force a smaller spall with a subconchoidal fracture. At some stage in the same process after the intermediate surface was produced by fracture, the wedge-shaped point of the pebble was broken squarely off. All of this fracturing was accomplished previous to the final embedding of the pebble in the tillite bed. Owing to the concavity of the fracture surfaces, they escaped striation, yet some slight scratching took place on the two larger surfaces.

Such fracturing is apparently due to the forcing of pebbles against the bed rock or against other rock fragments in the ice or by their being caught under boulders so as to have a great weight of ice concentrated upon them when they in turn are in contact with the bed rock.

<sup>1</sup> The color of the dry isolated rock is close to Orange 130, Klinkensiek et Valette: *Côte des couleurs* (Paris, 1908).

Where this type of pebble occurs on the surface of the ground at the present day as it does in the glaciated regions of eastern North America it might possibly be interpreted as owing its conchoidal fractures to the work of aboriginal man, but when firmly embedded in the glacial till of that district or in the tillite beds of Brazil no one would presume to connect it causally with human art. These crushed and bruised rock fragments with their sides well striated are common in south Brazil and along with other striated pebbles argue for the crushing, bruising action of a thick body of ice such as a glacier would afford. Even where stones of this type of contour occur isolated in fine shales into which they have been dropped from floating ice, the evidence as to their original handling by glacial action is equally good.

*Classification of Lithified Glacial Deposits and Derived Sediments.*—The lithological classification of sediments takes no account of genesis, its names, somewhat more carefully defined than in common usage, express ideas concerning the size of constituent particles, as in the terms conglomerate and sandstone; or designate vaguely a mode of fracture, as in shale with an understood composition of particles too small to be distinguished by the unaided eye. This simple primitive classification embraces all lithified glacial deposits when used with proper qualifying terms. The glacial deposits, so far identified, have given rise to two independent terms, boulder-bed and tillite, the first of which is conveniently vague, except for its reference to boulders, while the second covers a wide range of commingled rock fragments and particles having this in common that they were deposited by the agency of glacial ice. The study of modern glacial deposits would lead us to expect among ancient glacial deposits the lithified counterpart of each product of glacial action and the glacio-natant waters. Tillite, as consolidated till, would naturally be applied to all unstratified, unassorted deposits due to the direct agency of a glacier. The term thus is applicable to the rock of fossil moraines whether frontal, or ground-moraine, and to fossil drumlins. These varieties of tillite, since they are distinguished by topographic form, will not in the nature of the case take petrographic designations. The same remark applies to the assorted glacial gravels and sands forming the group of kames, eskers, and proglacial deltas, or gravel- and sand-plains. For their petrographic designation there is no distinctive term correlated with till and tillite. The coarser deposits are included in the conglomerates and the finer among the sandstones. The glacial rock-flours or clays, normally unweathered, finely divided clastic materials of complex mineralogical composition, often feldspa-

thic, should be sufficiently distinct from true clays to receive a specific name in the system of classification; but none occurs for modern deposits of this type in accepted usage. Such lithified glacial rock-flours may be called *pelodite* from *πηλώδης*, *es* (*πηλος*, *elidos*), *ite*, *clay-like rock*, in reference to the fact that these rocks often clay-like or shaly in texture and structure, when first formed may differ widely from typical clay in the very small amount of kaolin which they contain. Pelodite is to be differentiated from pelite also by its included glacial pebbles.

Closely associated with modern glacial deposits though distinct in origin and often very differently distributed is the fine mainly eolian deposit known as loess frequently derived from glacial moraines through their deflation by winds. Some of the finer sediments of the Brazilian Permian resembling clays seem to be of this origin. Such lithified deposits of loess may in analogy with tillite be called *loessite*.

With these preliminary statements it is to be presumed that the following tabulated classification of glacial deposits will need no further explanation.

| <i>Modern unconsolidated deposits.</i> | <i>Divisions depending on form.</i> | <i>Ancient lithified deposits.</i> |
|----------------------------------------|-------------------------------------|------------------------------------|
| Till .....                             |                                     | Tillite.                           |
| Boulder-clay .....                     | do.                                 |                                    |
|                                        | Moraine, frontal, ground-drumlins   |                                    |
| Glacial gravels. ....                  | Glacial conglomerates.              |                                    |
|                                        | Eskers, kames; glacial deltas.      |                                    |
| Glacial sands                          | Deltas and plains                   | Sandstones.                        |
| Glacial clays .....                    |                                     | Pelodite.                          |
| Loess .....                            |                                     | Loessite.                          |

*Classification of the Glacial Deposits of South Brazil.*—With the above simple classification in mind, it appears that the Permian moraines of south Brazil presents several facies of a glacial series, both stratified and unstratified.

In the tillite group must be placed the typical blue boulder-clays of the Rio Jaguaricatu section, the gravelly beds with large angular blocks, beds presumably of the ground-moraine or subglacial type. Unfortunately the limited exposures in the deeply forested river valley do not permit of a determination of the topography of these ancient beds of drift. In somewhat sharp contrast with the analogue

of true boulder-clays is the earthy type of tillite seen in the vicinity of Rio Negro. This I believe was deposited by floating ice in a shallow sea without stratification.

There are many beds composed of small rock particles embedded in an argillaceous ground-mass carrying only occasional striated stones which present some of the characters of flood deposits but which by reason of their glacial features it is to be presumed are tillite. In their yellow weathered state, their diagnosis is made with difficulty. They grade into "mealy" yellow sandstones.

The group of stratified gravels appears to be represented in the Orleans basin by the small ridge of conglomerate whose cross-section and horizontal extension recalls the form of an esker. The other occurrences of conglomerates as at Ponta Grossa do not show topographic features which enables one to distinguish them from gravels of non-glacial origin.

The dark colored shales in the Permian series, on the whole much less developed in thickness than the coarse sediments, have not been studied with reference to their glacial derivation. Where they contain marine fossils it is to be presumed that they have been worked over and any original glacial characteristic has been lost. Some of the fine clayey beds of sandy aspect which behave like loess in their weathered condition I suspect were originally loess, but this determination is difficult to make.

The large content of clay in the tillite beds of Jaguaricatu and Conchas on the Tibagy is not consonant with the derivation of these beds from the granites and gneisses of the present Serra do Mar region since such rocks under the direct attack of glaciation would produce predominantly gravelly and sandy beds with a minimum of clay or rock-flour of an argillaceous character. For this reason I am disposed to regard these clayey tills as worked over from the underlying Devonian shales and from the slates of the Pre-Cambrian series. This makes it possible to suppose that much of the material did not come from any great distance to the east of the Serra do Mar.

The tillite beds which approach nearest in their lithological characters to a solidified boulder-clay appear when fresh of a bluish color somewhat darker than the hue of the glacial brick clays of many parts of the United States of America. On exposure the rock weathers to a light brown or yellowish brown color often with streaks of reddish iron oxide.

This rock joints irregularly; frequently its fracture assumes a curving plate-like structure tending toward the dome structure and

actually attaining that of spherical separation, thus producing the bales shown in the Rio Negro section, characteristic of many weathering basalts, an effect coupled with the want of definite stratification within the stratum.

Once the tillite beds underlying sandstones are reached by dissecting streams or rivers, the overlying strata widen out with steep cliffs, the small streams falling over these rocks have falls, and, owing to the ready removal of the tillite and the growth of the main valley in this section, the side streams present the appearance of hung up valleys.

*Age of the Boulder-Beds.*—As commonly stated on the authority of Dr. Derby the boulder-bearing deposits are to be regarded as the equivalent of the Upper Carbonic or Permian glacial period now recognized in India, Australia, and South Africa. This Permian age of the beds in Brazil was accepted by Professor Branner in his *Geologia elementar* (Rio de Janeiro and São Paulo, 1906), and still more recently by Dr. I. C. White in his Report on the Brazilian coal field. In the same monograph, Mr. David White presents the most complete description and analysis of the flora of the south Brazilian field yet published. From this report it appears that the flora succeeding the conglomerates on the south in Santa Catharina are of the Lower Gondwana type which immediately succeeds the glacial beds in India and elsewhere in the eastern hemisphere. Dr. David White correlates the Jaguaricatu beds [Orleans conglomerate] and associated sandstones and shales of Dr. I. C. White with the Talchir beds of India, the Dwyka conglomerate of South Africa, and the basal conglomerate of the Permian series of Argentina.

*Divisibility of the Glacial Beds.*—The question is naturally asked whether there was one or more than one episode of glaciation or ice-action in southern Brazil. The facts concerning the distribution of conglomerates in this field are as yet too little known to enable one to give a satisfactory statement in reply to such a question. The localization of the typical tillite beds near the base of the series so suggestive of local contributions of débris complicates the question. If the conglomerate beneath the whitish sandstone at Serrinha Station with its glaciated fragment be of Permian age and pass, as it appears to, beneath the boulder-bearing beds exposed westward and southwards towards Lapa, then in that section there are evidences of two epochs of ice-action separated by the deposition of the sandstone beds which form the walls of the gorge of the Iguassú.

The tendency of the boulders to display themselves in a marked manner in certain zones often only a few feet apart is evidently a

result of deposition from floating ice and such distribution can not be depended upon as a basis for discussing advances and recessions of glaciers. It can only be said here that the evidence seen points to the existence of two horizons on which ice-action directly or indirectly arising from glaciation appears to be demanded.

It would seem from a comparison of the partial sections visited in the course of this Expedition that the boulder-beds are not persistently parallel formations, that the more typical tillite of one district may pass by gradation or intercalation of deposits into contemporaneous waterworn gravels or sands, now conglomerates and sandstones in another district along the strike of the beds. Thus in the sections along the Jaguaricatu in northeastern Paraná, the tillite with large angular blocks surmounts with few intervening feet of beds the white fine sandstone which appears to be a fairly persistent basal and pre-glacial member of the Permian series. In the latitude of Ponta Grossa the tillite appears at a much higher horizon, the apparent place of the Jaguaricatu tillite formation being taken by beds of waterworn pebbles. Again in the gorge of the Iguassú at Serrinha Station, if the beds be truly of Permo-Carbonic age at this horizon, a conglomerate with striated pebbles occupies an inferior position near the base of the series. At Orleans, yet further south, the tillite is replaced in the section by waterworn conglomerates possibly, though not certainly, laid down in the presence of ice in the manner of eskers.

This alternation from point to point along the present roughly meridional line of exposures, thus described of deposits approximately at the same level in the series, and probably more or less contemporaneous, finds a parallel in the existing deposits of glacial origin within the glaciated areas of Europe and North America. In traversing the glaciated region of the latter area we pass from north to south over belts of till with alternating strips of waterworn gravels and coarse sands and clays. In this particular case the deposits are successively newer in the direction in which the ice retreated, *i. e.* towards the north. We encounter another mode of deposition of alternating accumulations of ice-laid and water-laid drift, however, in which the likeness to the Brazilian distribution, so far as it is at present known, is equally close. That is where glaciers coming down either as distinct valley glaciers or as outflowing tongues from a central ice-cap reach the coastal plain or sea-floor at the base of a highland region so as to deposit till in the vicinity of the paths by which they reach the low grounds while the intervening areas receive only the waterworn débris. In south Brazil, what seems to be evi-

dence of an eastern origin for the glacial débris points to this latter mode of deposition rather than to the first above outlined.

Our knowledge of the Permian of south Brazil is limited to the narrow belt from which the overlying supposed Triassic beds have disappeared by erosion. The Permian is not represented as reappearing on the western flank of the broad shallow syncline which subtends the structure as far west as Cuyubá in Matto Grosso but it is probable that the Permian extends far beneath the Triassic cover.

*Boulder-Beds of the Argentine Republic.*—The brief references of Bodenbender (1895) to the occurrence of boulder-bearing beds beneath the Gondwana flora in the provinces of San Luis and Mendoza in central Argentina may be presumed, though this geologist does not infer their glacial origin, to indicate an extension of the Brazilian Permian geographic conditions to the south and west quite to the base of the Andes, thus practically carrying the peculiar geographic and climatic features of the Permian across the continent of the southern hemisphere from one shore of the Pacific Ocean to the other. Details concerning the agency concerned in the transportation of these Argentine deposits is as yet lacking and until the precise facts on this point are known it would be presumptuous to draw further conclusions from the deposits concerning the glacial problems of the South American Permian.

*Boulder-Beds of the Falkland Islands.*—Mr. Thorre G. Halle (1911, p. 115–229) reports the existence of a boulder-bed and typical tillite with striated flat-faced pebbles at the base of a Permo-Carboniferous series on East Falkland Island. Higher up in the section occur *Glossopteris*, *Gangamopteris*, *Phyllothea* and other members of the Gondwana flora.

The occurrence of glacial deposits in south Brazil and on the Falkland Islands carries with it the presumption that the boulder-beds beneath a Gondwana flora in Argentina are also glacial in origin whether or not they now show striae, which latter may yet be found on the small rock fragments.

*Gondwana-land. Did it include Paraná-land?* — Palaeogeographers relying largely upon the distribution of the fossil genera *Glossopteris*, *Gangamopteris*, and their plant allies of Permo-Carboniferous times with the associated glacial boulder-beds have gradually extended the name Gondwana-land from its original application to the Indian South African area so as to include the South American tracts in which traces of the Gondwana flora occur. To a certain extent the name has thus become designative of a set of geographical conditions

rather than a definitely determined continental tract of such vast extent. Some geologist of the distant future viewing the embedded traces of the Pleistocene glacial period of northwestern Europe and northeastern North America might with almost equal assuredness point out the existence of a vast continent embracing these areas and the included basin of the existing North Atlantic Ocean. The geographical conditions peculiar to Gondwana-land are found in India, Australia, and in South America from the Falkland Islands to the northern borders of the state of São Paulo. Representatives of this flora apparently of later date occur as far north as the Mexican state of Oaxaca, there with plants of a Triassic facies, *Williamsonia*, *Zamites*, *Otozamites*, etc. (Wieland, 1909, p. 441-442). For the purpose of designating the larger tracts in which this Permian flora and the glacial conditions occur, Gondwana-land has thus lost its original limited meaning. The south Brazilian field with its boulder-beds and later Triassic trap sheets constitute a well-defined geological province to-day for which the name Paraná-land is quite appropriate. It is to be presumed that Paraná-land was conterminous with land southward over Argentina and thence to the continental island group of the Falklands. All three of these Gondwana areas lie within that of the existing continental block.

The question of the connection of South America with Africa in Permo-Carboniferous times may be stated in other terms in a more general form to be that of the origin and history of the Atlantic Ocean basin, which Suess has discussed in no uncertain way. The fact that there is no recognizable trace of the Atlantic Ocean along its existing borders in early Triassic times, except for a narrow sea marginal to the Mediterranean tract, and the fact that the Atlantic is a narrow and not deep sea are quite consistent with the hypothesis of the origin of this depression since Lower Triassic times. Certainly the assumption of an Atlantic trough in Pre-Triassic times having anything like the present extent of that basin must be abandoned as being without sufficient geological evidence. Viewed in the light of Suess's masterful generalization of the geology of the Atlantic shores, we find no trace of the South Atlantic Ocean during the Carbonic period until the possible marine episode of the Permian epoch in South Africa<sup>1</sup> and in south Brazil if indeed these waters penetrated these continents from the Atlantic basin. In Brazil it is more probable that the sea invaded the state of Paraná from the west. Without

<sup>1</sup> Halle notes the report by Schroeder of marine fossils above the Dwyka conglomerate in German southwest Africa. *Op. cit.* p. 203.

further details concerning the African Permian sea it is possible to admit a shallow sea in the Atlantic area as far north in that district as the southern tropic, but this at a later stage than the epoch of principal glaciation in Africa. Both in Africa and South America, the marine beds of the Permian demand land near sea-level immediately before and after the invasion by the sea. Little else can at present be argued from their occurrence.

The volcanic islands which stake out the mesial line of the Atlantic and its connection with the Arctic Ocean hug the shores of Europe and Africa rather than those of the Americas. Since those volcanoes whose substructure is known are associated with crustal displacement involving either horizontal or vertical motion or both and particularly the latter mode of derangement, it is probable that we see in these islands the indirect evidences of a geologically recent movement of the Atlantic bottom which we know from Iceland was well under way in Miocene times. Along the shores of North and South America which trend northeast and southwest we find traces of downsinking of the land in Cretaceous times. In the North Atlantic region, the Pan-Appalachian mountain-chain extending from the dislocated structures of the Rocky Mountains across the southern United States to the coast in Newfoundland can be traced north of the Alps in Europe into Asia but is interrupted in the Mississippi embayment and by the North Atlantic basin which cuts across the folded structures as if they had sunk to form the present ocean floor. These and other indicated changes of depth and outline of the Atlantic province make it incredible that in Permian times the basin had much of its present length, breadth, and depth. We may conclude therefore that the geologist is free to converge the coasts of Africa and South America in Permian and earlier Carboniferous time as closely as any biological facts and geological evidences of land may demand for their explanation.

In south Brazil all the known facts from the Atlantic border demand an extension of land beyond the present coast in late Palaeozoic time, but how far towards the coast of Africa we can not say. The discovery of the Gondwana flora in the Falkland Islands makes it possible to effect the distribution of these plants from Australia into South America by way of the Antarctic continent. Possibly Africa also received its population by this route or more likely from India. The revealing of the geology of the Antarctic continent receives from this state of the problem of Gondwana-land a renewed interest.

*The Permian Glacial Problem.*—In the foregoing account of the

Permian boulder-beds of Brazil I have set forth the evidence for the existence of glacial discharge of débris at or near sea-level. The occurrence of boulder-beds, presumably likewise of glacial origin, in central Argentina is supported by the finding of tillite in Permian beds on the Falkland Islands. These occurrences practically complete the evidence that the Permian glacial traces occur on all lands outside of the Antarctic circle in the Southern Hemisphere from shore to shore of the Pacific Ocean. In South America the evidences exist from the tropic of Capricorn southward to 52° S. L. They occur in South Africa coextensive with the sediments of the time. In Australia they occur over a vast area in the eastern part of that continent and in Tasmania. It is now apparent that no shift of the polar axis in Permian time will bring these evidences of glaciation into a better circumpolar distribution than they now display.<sup>1</sup> Thus those hypotheses which attempt to account for Permian glaciation by a shift of the earth's axis of rotation have not been called for by any facts which we now possess. The discovery of tillite in the latitude of 52° S. diminishes the difficulty of the climatic problem by removing the supposition that the glaciation was dominantly a subtropical affair. The general absence of existing land in the Southern Hemisphere in the latitude of the Falkland Islands probably accounts for the present lack of signs of Permian glaciation in high latitudes. The Antarctic continent is too little known as yet to premise what evidences future explorations may bring forth. The facts upon which the Permian glacial period rest still come largely from the Southern Hemisphere where at present the ratio of area of land to sea is so small.

In the Northern Hemisphere the Permian glacial deposits remain most typically developed and best known in the subtropical region of India, in the Salt Range and Talchir districts. But traces of ice-action in high latitudes are not wanting and are coming continually to light with the more critical diagnosis of the conglomerates of the late Palaeozoic terranes. The Permian breccias of England regarded by Ramsay as of glacial origin as early as 1855 appear to be now accepted as such by English geologists.

These traces occur in Latitude 53 N. A. Julien supposes the coarse breccias of the Carboniferous in France to be of glacial origin, and Kalkowsky attributes to glacial action a pebbly shale among the Carboniferous rocks of the Frankenwald. These occurrences in Europe pointing to some kind of ice-action if not in every case to the

<sup>1</sup> Halle draws the same obvious conclusion from his discovery of the tillite on the Falkland Islands.

existence of glaciers demonstrate the wide distribution of the climatic conditions producing Permian glaciation and where the traces of ice-action exist in horizons below the Permian show that the glaciation of that period was induced by causes not suddenly brought into play.

In North America in latitude 42° S., Messrs. R. W. Sayles and L. A. Laforge have called attention to a remarkable breccia at the top of the Roxbury conglomerate south of Boston in which many of the peculiarities of glacial till occur, including a few striated pebbles. The precise position in the time scale of this bed is not known from contained fossils in the local series but its relations to the Narragansett coal field on the south make it presumable that the beds are Permian. In Oklahoma in about latitude 35° S. erratic blocks occur in a shale of Subcarboniferous age. The striae on these transported stones are of post-depositional origin due to rock motion but the transportation of the boulders remains unexplained except by floating ice. The evidence from North America, as yet meagre, points to the same conclusion as that derived from the distribution of breccias and conglomerates of Carboniferous and Permian age in Europe. So far as the facts from North America go, local glaciers are the most that at present can be postulated.

What combination of geographic with atmospheric conditions brought about Permian or even Pleistocene glaciation we do not know with any degree of certainty. All our hypotheses of glaciation postulate glaciers and ice-sheets engendered from the fall of snow. It is possible, though not now seemingly probable, that under the peculiar recurrence of hailstorms which are, in the existing regime unusual forms of precipitation, masses of ice might accumulate in tropical and subtropical areas where snow never falls.

Hail and allied forms of frozen rain-drops enter more largely into glaciers in existing mountains than is perhaps commonly recognized. Kaemtz (1845, p. 380-382) gives several citations to show that hail frequently falls on the Swiss Alps. It is probable that no small amount of hail enters into the structure of Swiss glaciers. De Saussure states that during a stay of thirteen days on the Col de Geant at an elevation of 3,428 meters he was struck with the frequency of hail and sleet which he observed eleven times. Balmont experienced a shower of hail during the night that he passed on the summit of Mont Blanc and Paccard found much hail beneath the snow with which the summit is covered.

Edward Whympers (1892, p. 164 *et seq.*) describes frequent falls of hail within the region of glaciers on the mountains of Ecuador. When

nearly 16,000 feet high on the slope of Sincholagua on Feb. 23, 1869, a furious hailstorm took place followed after a lull by a fall of snow mixed with hail which gave way in turn to a thick fall of large flakes of snow. There was a glacier at this time on the mountain. Again in describing his ascent of Antisana on March 9, 1869, he states that at the height of 15,984 feet at the top of a moraine on the right bank of the glacier a fierce hailstorm occurred about 4 P. M. and snow fell heavily afterward.

Charles Darwin (1845, p. 115-116, or 1887, p. 115-116) describes a remarkable fall of hail in Argentina near the foot of the Sierra Tapalguem between Bahia Blanca and Buenos Aires on the night of Sept. 15-16, 1833. The hailstones were said to have been as large as apples. The same distinguished naturalist cites the account of the Jesuit Brobritzhoffer who states that in the region much further north hail fell of an enormous size and killed vast numbers of cattle, hence on this account the Indians called the place *Lalegraicavalca*, meaning the "little white things." Darwin also quotes Dr. Malcolmson to the effect that this observer witnessed in India in 1831 a hailstorm which killed large birds and injured cattle. These stones were flat; one was ten inches in circumference, and another weighed two ounces. They ploughed up a gravel walk like musket balls, and passed through glass-windows, making round holes but not cracking them.

Sir Joseph D. Hooker (1854, 1, p. 405) gives a personal account of a hailstorm which took place on the 20th of March, 1849, on the south slopes of the Himalayas. "A violent storm from the southwest occurred at noon, with hail half an inch across and upwards, formed of cones with truncated apices and convex bases; these cones were aggregated together with their bases outwards. The large masses were followed by a shower of the separate conical pieces, and that by a heavy rain. On the mountain this storm was most severe, the stones lay at Darjiling for seven days, congealed into masses of ice several feet long and a foot thick in sheltered places; at Purneah, fifty miles south, stones one and a half inches across fell, probably as whole spheres."

According to Lieut.-Commander Gorringe, U. S. N., (1873, p. 331) the city of Rio de Janeiro was visited by a storm with a heavy fall of rain and hailstones on October 10, 1864. The hailstones were as large as pigeon's eggs. "Branches of trees were broken and twisted off, and the foliage destroyed by the hail, which poured down in such quantities that piles of it remained at the corners of the streets until the afternoon of the following day."

Thomas Russell (1895, p. 98-100) gives a few statistics regarding the falls of hail as follows:— Hail falls during thunderstorms in summer and during the hottest part of the day. It rarely forms layers six inches thick. On Aug. 13, 1851, hail fell in New Hampshire to the depth of 4 inches. On July 24, 1818, it fell on the Orkney Islands to the depth of 16 inches, on August 17, 1830, in Mexico City, to the depth of 16 inches. In the Yellowstone valley in Montana a fall of 14 inches has been recorded. . . . Hail is more common at 15,000 feet than at sea-level, it forms at elevations from 5,000 to 16,000 feet; the greatest size of hailstones is found below 5,000 feet. It falls most frequently on the lee side of rising ground. . . . There are on the average fifteen hail storms a year in France, five in Germany, and three in Russia.

In the Antarctic region hail now falls but rarely. Commodore Wilkes alone reports two instances. Fog there gives rise to some crusts of ice. (Fricker, 1900, p. 244).

Alfred R. Wallace (1892, p. 299) states that he had good authority for hail having once fallen on the upper Amazon at a place only three degrees south of the equator and about 200 feet above the level of the sea. Humboldt (1852, 2, p. 217) instances a case of hail falling at Paruruma in the Orinoco valley on a plain near sea-level. He states that hail in the tropics generally falls only at an elevation of 300 toises (about 600 meters).

The Shaler Memorial Expedition encountered in July, 1908, at an altitude of 900 meters on the campos of São Paulo between Bury and Faxina (p. 13), a hailstorm which covered the ground as thickly with hail as do many similar storms in New York and New England.

I cite these instances of hailstorms with their attendant circumstances because hail presents us now with a means of precipitating ice at low altitudes in regions near the equator where snow never falls. Hailfalls appear to increase toward the hot regions of the globe and to diminish in frequency of occurrence towards the polar tracts. Thus the probability of glaciers originating from hailfalls in subtropical regions would seem to be as great as from snowfalls, provided the hailstorms came frequently enough to overcome the effect of melting due to the higher temperature of those parts of the earth's surface. Hailstorms like thunderstorms are secondary movements of atmospheric vapor normally engendered in the wake of cyclones of far greater size and with a much longer path, and we do not at present know what geographic conditions, if any, would cause in Permian times a succession of hailstorms sweeping with the regularity of

cyclones of the existing atmospheric circulation over the glacial fields. The distribution of land and sea in the Southern Hemisphere was then so different from what it now is, particularly in the Atlantic and Indian regions, that, while we may freely speculate upon a different system of distribution of aqueous vapor, it is at present impossible to construct an unassailable theory.

The "pendulationstheorie" of H. Simroth (1907) which is but a modification of the idea of a shifted axis of rotation does not better than the original conception explain the phenomena of distribution of Permian glaciation for the reason that no shifting of polar climates will bring the glacial deposits in the polar regions. Dr. Wilh. R. Eckardt (1910, p. 125-127) has well observed in connection with the above mechanical hypothesis that Sumatra, assumed to be one of the fixed equatorial poles of pendulation in this speculation, is placed on the borders of the principal area of Permian glaciation and hence no essential shift is accomplished.

The recently elaborated hypothesis that glaciation may be brought about through the temporary reduction of the amount of carbon in the earth's atmosphere appears to fail as an adequate explanation of the phenomena of glacial periods since the view does not explain the succession of epochs of glaciation and deglaciation in the Pleistocene period. Four times in this period the ice-sheets apparently came on and went off. If the abstraction of carbon in the form of coal and limestones in the preglacial period led to the first ice accumulation and advance, the hypothesis leaves unexplained the shortly succeeding ice advances between whose dates no corresponding appreciable reduction in the carbon is registered by rock-making in the earth's crust.

As we do not know with any certainty the cause of the latest glacial periods so near our own times, it is evident that the geographical conditions of the Permian must be thoroughly ascertained before we can construct a plausible explanation of a glacial period so remote and taking place on lands whose contours are as yet drawn with too much conjecture. Certain lights appear however to be burning as guides to the path which shall lead to the discovery of the probable cause of Permian glaciation. These may be briefly summarized as follows:—

The axis of the earth appears to have lain in Permian times where it does now. This excludes a favorite group of hypotheses.

The glaciated lands of south Brazil and German southwest Africa were in Permian time at or near sea-level. This does not exclude the extrusion of glaciers from highlands to the sea-border provided the highlands lay over the site of the Atlantic basin.

In the Northern Hemisphere on the existing shores of the Atlantic Ocean glaciated stones are found entering into the contemporaneous marine deposits much farther equatorward than those produced by the action of coast-ice and the same extension is true for the occurrence of glaciated ledges. Thus on the Atlantic coast of North America glaciated ledges and deposits of true glacial till line the shore of the United States as far south as New York Narrows in latitude  $40^{\circ} 30'$  north; no modern observer has described stones or ledges bearing distinct traces of coast-ice action within this belt south of the British possessions, though it is to be acknowledged that thin sheets of coast-ice form in winter and may do some geological work of this character. The reason for this greater equatorward extent of glacier-ice as contrasted with ordinary sea-ice is due to the extent to which glacier-ice may be pushed equatorward beyond the gathering ground of the glaciers. In a like manner, glaciers originating on high lands in low latitudes may reach the sea-level and impress that region with marks of glaciation where the normal sea-level temperatures at the time preclude the existence of coast-ice. It can not be too much insisted upon, therefore, that glaciation is of all forms of ice-action that most likely to be met with in any marked degree at sea-level in low latitudes. Hence it is the more reasonable to assume that the Permian ice-deposits represent the existence of glaciers in the regions where these coarse accumulations occur, invoking as we may where the geologic evidence is permissible a favorable geographical relief such as now controls the distribution of glacial ice at one place or another on the earth's surface.

The rôle which hail might play in producing glaciers in subtropical regions as a complement to snowfall in higher latitudes and high altitudes is tentatively suggested as a factor in Permian glaciation, but the feasibility of the thesis encounters some of the same objections which meet the accepted origin of glaciers in snowfall.

There are accumulating evidences of the existence of glaciation in the Northern Hemisphere in Permian time, and there are not wanting signs of ice-action, probably floating ice, in the preceding Carboniferous epoch, facts which assist in the attempt to devise hypotheses.

The tendency of the geologic evidence is towards the recognition of glacial conditions independent of latitude which points to a weakness of the climatic zones, a feature characteristic of Palaeozoic temperatures, in which non-glacial climates show no zones corresponding to the present ones.

The hypothesis of internal heat controlling surface temperature

~~which has been advocated by Mr. Meraden Mason finds little support~~

# ERRATA AND CORRECTIONS.

| Page      | Line   |                                                                                                        |
|-----------|--------|--------------------------------------------------------------------------------------------------------|
| 5         |        | Read Tubarão for Tuberão, and so at pp. 45, 46, 70, 71, 73, 92.                                        |
| 10        | 10 up. | For Napareth read Nazareth (?).                                                                        |
| 14        | 8 up.  | Omit "Middle" before "Devonian."                                                                       |
| 17        | 10     | Read Coroados for Coroadas.                                                                            |
| 29        | 17     | Read Rio de Peixe for Rio Peixe.                                                                       |
| 30        | 7 up.  | Read Talcahuano for Talcahuana.                                                                        |
| 30        | 17 up. | Read leached for leeched.                                                                              |
| 35        |        | Right hand side of fig. 6 should be at bottom.                                                         |
| 37        | 22     | Read "statute" after "228."                                                                            |
| 39        | 4 up.  | Insert "to" after "according."                                                                         |
| 46        | 9 up.  | Read espessura for espessure.                                                                          |
| 56        | 2 up.  | Read Capivary for Capiavary.                                                                           |
| 69        | 2      | Change period to comma before "That," and read "the example shown in Plate 24" for "That in the view." |
| 82        | 16.    | Read continents for continent.                                                                         |
| 86        | 5, 12. | Read N for S after degrees of latitude.                                                                |
| 93        | 7 up.  | Read Serra da Esperança for Serra Esperança.                                                           |
| 94        | 16 up. | Read lay for laid.                                                                                     |
| 98        | 6 up.  | Read Serra da Esperança for Serra do Esperanço.                                                        |
| 103       | 9 up.  | Read Murtinho for Murinho.                                                                             |
| 117       |        | Read 1846 for 1891 in parentheses.                                                                     |
| 134       | 10     | Read com for con.                                                                                      |
| 135       |        | Read Lyell for Leyell.                                                                                 |
| 136       | 3 up.  | Read schistos for schistes.                                                                            |
|           | do.    | Read Taubaté for Taubeté.                                                                              |
| 137       | 5      | Omit 2nd line reading "Papers" etc.                                                                    |
| Plate 1.  |        | Read Valle do Retiro for Val. do Ritiro.                                                               |
| Plate 12. |        | Read Gorge for Cañon.                                                                                  |

~~In the Northern Hemisphere on the existing shore.~~

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i  
i  
i

which has been advocated by Mr. Marsden Marson finds little support in the geological evidence derived from the occurrence of rocks at a high temperature over large areas beneath the surface. The great Triassic trap outflows of Brazil were erupted but shortly after the Permian glaciation in that field. During the epoch of glaciation the magma was still confined within the crust but had no recognizable effect in controlling surface temperatures or in preventing glaciation of the Permian land surface.

## VI. THE TRIASSIC TRAP PLATEAU.

Overlying the Palaeozoic strata of the southern Brazilian highlands and either intruded in or interstratified with a group of red beds of presumed Triassic age is a series of trap sheets, mainly lava-flows, of vast extent, comparable in age and geological position with the basic igneous rocks of the so-called Newark group of the eastern coast of North America, and rivalling in their present surficial extension the Cretaceous lava-fields of the Deccan of peninsular India if not also the more recent lava-flows of the Columbia and Snake River basins of western North America. From the northwestern part of the state of São Paulo and the borders of Minas Geraes where the trap rests upon the Pre-Devonian schists, these sheets of trap form high plateaus broken through by the tributaries of the Rio Paraná as far south as central Rio Grande do Sul. From the sea-border near Porto Alegre in the latter state the trap formation extends westward according to the report of Dr. M. A. Lisboa as far as the Serra do Maracajú in Matto Grosso at a point 460 kilometers east of the Rio Paraguay or nearly 12 degrees of longitude west from Rio de Janeiro. The trap formation has been recognized over a breadth of country five degrees in longitude and some eight degrees in latitude between the parallels of 20 and 28 degrees south. The area in which these rocks dominate the surface is in round numbers about 100,000 square miles or approximately a region as great as that of the state of Nevada in North America.

In describing the geological features of the trap plateau in the Rio Pelotas basin, I shall use for the igneous rocks the non-committal term *trap* since it avoids the inexactness which might arise from the general application of such terms as basalt, augite-porphry, etc., to which kinds of rocks certain parts of the trappean series have at one time or another been referred.

As is stated more explicitly in what follows I include in the area of

the Pelotas plateau a large tract about Lages in Santa Catharina in the headwaters of the Rio Pelotas from which the trap has been denuded so as to leave the Triassic red beds exposed at the surface. This region is separated from the trappean plateau of Paraná by the Rio Iguassú as far west as Porto da União da Victoria, some leagues west of which point the dissected trap plateaus of the southern Brazilian coastal states merge in the longitude of the Rio Paraná into a broad sheet with little topographic differentiation. Throughout Santa Catharina and Rio Grande do Sul the border of the trap area gives rise to high escarpments capped by trap sheets overlooking the Permian sedimentary tract. This escarpment with its varying relief and declivity receives local names.<sup>1</sup> South of Rio Negro it is known as the Serra do Espigão which attains an elevation exceeding 4,000 feet. The main, almost unbroken, escarpment farther south and east is known as the Serra Geral.

*The Trap Escarpment.*— This line of escarpments has been interpreted as a fault cliff and as a true retreatal escarpment due to differential erosion. Doubtless small faults intersect the trappean series as elsewhere in the region but the descriptions of others and my own observations upon the escarpment in the Serra do Espigão and at the head of the Rio Tuberão leave no question in my mind that the escarpment is the effect of differential erosion on the Permian and Triassic beds capped by resistant sheets of trap.

At the head of the Rio Tuberão the Serra Geral is a typical steep-walled trap escarpment below the base of which erosion spurs and ravines of the sedimentary beds comprising the Trias and Permian are developed in sharp relief under the active headwater attack of the Rio Tuberão and its tributaries.

Inland in the region of the Serra do Espigão the alignment of the escarpment is less simple in its curvature. Siemiradzki in a section reproduced by Suess in "La face de la terre" assumes a normal fault along this line as he does also in the case of the "cuesta" of the Devonian sandstones but without structural evidence, and here also the topographic development of the rocks is simply a matter of secular denudation as shown in the geological section drawn by Derby and published by Branner in his *Geologia elementar*.

Siemiradzki represents the Serra do Espigão as a ridge of lava piled up above a dike. The northwestern spur of the Espigão forms a high terraciform ridge standing out above the trap plateau south of the escarpment but the table-like masses of which the ridge is composed indicate that it is a portion of the trap sheets left standing out in

consequence of erosion. In the section which can be constructed from the exposures along the road from Rio Negro to Lages at the pass through Collectoria it is possible that a fault can be traced cutting off the Espigão from the main mass of trap on the south at the right of the section in Fig. 24. But this interpretation of the



FIG. 24.— Section across the Serra do Espigão at the Collectoria on the road from Rio Negro to Lages.

tilted beds at the bottom of the valley and the apparently lower level at which the trap lies south of the stream crossing demands a throw of the normal fault on the south side in a manner nowise supporting the hypothesis that the escarpment is due to a fault. This northerly steep dip has by some been regarded as cross-bedding and is stated to occur elsewhere along the trap escarpment in the underlying sandstones.

*Number of the trap sheets.*— It is stated that there are four trap sheets or sets of sheets in the trap mass of the Serra Esperança on the



FIG. 25.— Cross-section of the Trap plateau from the Rio Negro to Lages. 1 (dotted). São Bento beds. Triassic. 2 (right lined). The Collectoria trap sheet. 3 (cross lined). The Corisco trap sheet. 4. The Third (and Fourth?) trap sheets.

north of the valley of the Rio Iguassú. In Dr. Derby's section the trap is diagrammatically represented as if composed of surface flows. The number of flows or sheets entering into the plateau between the Serra do Espigão and the sandstone area about Lages was not definitely determined by observation upon the ground but the plotting of the profile of the route and the outcrops of sandstones encountered in the trapean tract leads to the conviction that along this route there are at least three great sheets of trap separated by sandstone beds. The subjoined figure section (Fig. 25) gives the approximate profile and geological section along a line paralleling the road from

Rio Negro to Lages. The elevations are from aneroid readings and are subject to such a correction that the altitude as given may be 100 feet out. The structure as drawn involves a gentle folding of the trap sheets in accordance with the varying dip of the strata between the southern edge of the trap and Lages. The inclined bedding seen in certain sections exposed in stream bottoms is interpreted as due to displacement indicating downthrow along faults or else sharp flexures. An interpretation of the structure regarded by the writer as less probable than that above given demands the presence of four trap sheets and requires the existence of a fault of several hundred feet downthrow along the southwestern border of the trap in the upper waters of the Rio Canoas.

In either construction the trap in the pass over the Serra do Espigão at the old Collectoria appears as the lowest in the series. The north-



FIG. 26.—Trap ridges of northwestern arm of Serra do Espigão, seen from heights near Corisco.

western branch of this trapean ridge as seen from the heights near Corisco shows three distinct tabular masses rising above a common level which may be that of an underlying trap sheet. A four-fold division of the trap series is there strongly suggested. The fact that one of the great trap sheets may consist of more than one flow without intervening beds of sandstone or shale makes it impossible to rely implicitly upon topographic profiles. The locality laid too far from our route to be geologically examined.

The lowest bed of trap on this route which I have called the Collectoria sheet is relatively thin, according to a rough estimate given below and based on a mule-back transit, about 300 feet. It appears to form the surface along the line of the Lages-Rio Negro Road as far south as the crossing of the Rio Correntes, where the second sheet or Corisco flow is encountered. Along our line of route the upper surface of the first flow or sill was not seen and though I am inclined to regard it as an effusive sheet I am not able to point out local evidence for such a conclusion.

The Corisco sheet is, according to my rough measurement, the thickest of all and has the greatest surface exposure in this district. This sheet forms the surface of the plateau along the road from Corisco to Coritybanos. The trap is moderately dissected by numerous streams. Amygdalar trap abounds on the higher parts of the surface

affording presumptive evidence that the sheet is an effusive flow. The road from Coritybanos northwestward to São João traverses the deeply eroded surface of this sheet across the campos of Guarda Mor. In fact the upper waters of the Rio Marombas and its tributaries, the Rio das Pedras and the Correntes, mainly lie on this surface.

South of Coritybanos there appears to be good reason for considering the high trap mass there encountered as an outlier of a third sheet limited on the south by the Rio das Cachoeiras. This mass seems on account of the sandstones which crop out on its southern slope to be divisible into two beds of basalt. If this interpretation is correct, the top of the hill is a remnant of a fourth trap sheet in this area.

*Thickness of the Trap Sheets.*—Exact estimates of the thickness of the several trap sheets are not possible from the notes I have; but the following approximations are thought worth recording as giving the order of magnitude of the thickness of the sheets. The estimate postulates the supposition that the base of the Corisco sheet is to be seen on the south bank of the Rio Correntes at an altitude of ca. 3,400 feet, and that its upper surface passes beneath higher beds in the vicinity of Coritybanos at an elevation of ca. 3,200 feet. By graphic construction the sheet is found to be ca. 600 feet thick (190 M.). The overlying trap remnant south of Coritybanos consisting possibly of two flows must be nearly 600 feet (190 M.) thick with the intercalated sedimentaries. The basal bed or *Collectoria* sheet on this estimate would be about 300 feet (95 M.) thick. The total thickness of the trap sheets would thus be about 1,500 feet (475 M.).

*Origin of the Trap Sheets.*—No known volcanic necks or explosive vents have been reported in connection with these sheets. In the region which I visited the succession of sheets is suggestive of surface flows and the Corisco sheet is very probably of that nature. Far to the southeast in Rio Grande do Sul, Dr. I. C. White has described the occurrence of sills and intrusive masses of trap as if breaking up through the sediments into the horizons occupied by the sheets in a manner to support the theory of fissure eruptions for the origin of the true flows of this region. In our journey across the sandstone tract north of Lages one noteworthy dike was encountered presenting characters which bear upon the mode of origin of the trap sheets. That occurrence will now be described.

*The Dike with Inclusions North of Lages.*—About 8 kilometers north of Lages on the road to Coritybanos there is to be seen a remarkable dike agreeing in petrographic character with the neighboring trap sheets on the north and probably to be regarded as a feeder to one of

them. This dike crosses the road in a direction N. 70° E. (magnetic) having a width at the road of 23 meters (75 feet). The sandstones on the north side of the dike strike north-south (magnetic) and dip ca. 5° west. The sandstone on the south side of the dike strikes N. 23° W. (magnetic) and dips 7° west. West of the road the dike is traceable by means of small weather-boulders in a brook for about 1,098 meters (3,600 ft.) but the trace of the dike to the east of the road was not followed. (See Plate 18.)

In the disintegrated rock of the dike there are crystals as large as a hen's egg of a now rusty black augite and large flakes of a black mica carrying holes from which some included mineral of earlier genesis has been dissolved out. A soft, white, partly altered, mica is probably bleached biotite. The feldspar constituent was not observed.

The most striking feature of this dike is the large number of inclusions of foreign rocks which it contains. These constitute at the exposure in the road quite one half of the volume of the dike and comprise at least the following varieties of older rocks, viz:—

Red sandy shale in fragments up to 51 cm. (20 inches) diameter.

Red shale; also a black shale.

Coarse grained basalt with lathe-shaped feldspars.

Fine grained basic rock.

Amygdaloidal basalt.

Greyish amygdaloidal basalt, less vesicular lava than the preceding.

A fine-grained, dark, thin-laminated rock weathering white, origin not determined.

The fragments of sedimentary rock may well be regarded as disrupted from the walls of the fissure which appears to have been the locus of a vertical displacement of the strata. Presumably the fragments came from underlying strata though they may just as well have fallen in from above. The vesicular lavas of different types, unless there are flows buried beneath the Lages area of sandstones, contrary to my own determinations of the geological structure and those of Dr. I. C. White, must have been derived from overlying lavas. Though rarely, amygdales form vertical bands in dikes, they are characteristic of lava-flows or of lava which has been raised to the vent of a volcanic conduit. This dike apparently communicated in its time with the surface and permitted lavas already extravasated and cooled to yield fragments which sank in the still fluid magma of the dike. So much of the history which appears in the nature of the phenomena leads to the further conclusion that the dike communicated at the time of the infalling fragments with the Corisco, or some yet

higher sheet. From these observations it is to be inferred that fracturing of the underlying sandstones and the migration of the basic magmas towards the surface went on during the period of great trappean outbreaks presumably with a foundering of a vast area which became flooded with successive sheets of lava from many fissures. Between one and two kilometers south of the dike above described another but much narrower basic dike about a foot wide crosses the mule path near a small stream. An extended search would probably reveal many other dikes once serving as feeders to the overlying trap sheets.

*The Lages Area.*—For several leagues around Lages the trap sheets have been denuded leaving the Triassic sandstones and shales of the São Bento beds of Dr. I. C. White's report at the surface apparently in an anticlinal dome. On the northern margin of this tract the trap overlooks it with a well-defined, but much notched, escarpment rising a few hundred feet above the general level. At the eastern limit of vision from the Lages road, a conical outlier of the trap forms a prominent hill, showing that along this line, as on the face of the escarpment overlooking the Permian territory, erosion and not faulting has produced the trap escarpment.

*The Lake Basins of Santa Catharina.*—"La province de Santa Catharina est couverte de petits lacs." (Malte-Brun. *Geographie* 1857, 6, p. 687.) In the interstream areas of the trap surface large tracts frequently depart widely in their slopes from the sculptured forms produced by running water. The surface becomes undulating with saucer-shaped pits always opening out on one side towards the drainage way of the district. As the small basins become deeper and more numerous, inosculating rounded ridges rise between them, giving such tracts the appearance of New England kame-kettles and their winding kame-ridges. In the pits there are shallow lakes or pools. These depressions and ridges are evidently the work of long continued secular weathering of the basalt combined with the removal of the products of disintegration and decomposition.

Most of these basins were at the time of my visit more or less occupied by standing water, some of them forming shallow lakelets in which grew a brilliant green grass. Other basins presented the appearance of level meadows from the filling of presumably residual clay and vegetable matter which they contained. At São João on the trap plateau south of Porto da União, a pit some three or four feet in depth had been dug in one of these floored depressions, showing beneath a few inches of vegetable matter a light colored clay evidently the product of decomposition of the trap rock.

The exposures of trap on the rounded ridges which separate the basins are usually crusted with superficially segregated oxides of iron, and loose weathered blocks are not infrequently seen in positions to indicate the almost complete absence, for a long geological period in the past, of any transporting agency such as sliding snow, ice, or run-

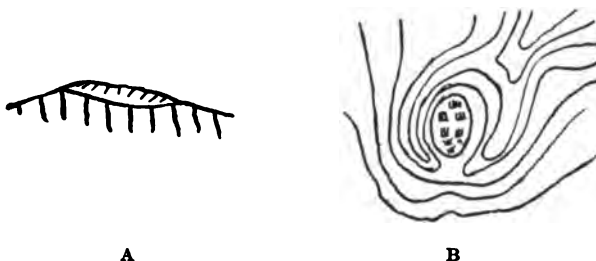


FIG. 27.—Basins of decomposition on the Triassic trap plateau. A, cross-section of basin overhanging a stream valley. B, contour map of lakelet converted into a swamp. Santa Catharina.

ning water. There is thus no reason for supposing that the basins are due to other causes than deep secular decay and the slow wasting away of the rock under a moderate rainfall. That these weathered basins are of great antiquity is obvious from the consideration of the mode of origin which thus may be ascribed to them. There is no clear local indication of the geological date of beginning of the basins. Inasmuch as they abound on the surface of the Corisco lava-flow above described they, in this instance, are more recent than the erosion of the overlying sheets of trap. I saw nothing in them by which to distinguish Pleistocene from Tertiary processes unless it be the deposits of clay which would argue for probably a Tertiary date as the time of beginning of the corrosion, but they may be early rather than late Tertiary.

Such solution-basins are not limited to the trap plateau but are to be seen here and there on the Permian area in São Paulo where springs find their way to the surface.

Mr. T. A. Allen (Derby, 1906, p. 388) has described pot-holes often of great size and containing water, in the gneisses to the east of the Serra do Esperanço on the plains of Bahia. He regarded these pits as due to a peculiarly localized action of disintegration.

Professor Pumpelly (1879, p. 136) has called attention to the manner in which deep secular weathering followed by a period of active erosion as by ice would result in the production of a topography quite unlike that of normal land sculpture by streams. He notes that "as masses

of decomposed rock may be observed to a depth of over 100 feet, the surface of the still solid rock underneath presents ridges and hollows, succeeding each other according to varying durability under the influence of percolating carbonated water. In this kind of weathering, where erosion does not come into play, it is evident that the resulting topography must, in some important respects, differ from that of an ordinary surface of superficial denudation. In particular, rock basins may be gradually eaten out of the solid rock. These will remain full of the decomposed material, but any subsequent action, such as that of glacier ice, which could scoop out the detritus, would leave the basins and their intervening ridges exposed."

## VII. GEOMORPHOLOGY OF SOUTH BRAZIL.

In the preceding chapters so much has been stated concerning the form and relief of the tableland of south Brazil, in describing the structure and position of the Permian glacial beds, that little remains in treating specifically a sketch of the geomorphology of the region than to summarize the matter in more systematic terms with the added enumeration of certain details.

Regarded as a land form south Brazil is an elevated tableland with a short steep slope descending to and below the Atlantic sea-level and a long gentle slope towards the interior of the continent. The surface of this warped mass appears to have been in Cretaceous times much more nearly a plane. Since its elevation and warping it has been dissected by streams which have etched out the structure of the westward dipping beds of the long westward slope into lines of escarpments formed of the edges of the harder more resistant beds overlooking lowlands.

For convenience of treatment the region may be divided into two districts which by their geological nature and relief at once impress the visitor to Brazil. First, the steep coastal border of the Serra do Mar, and second, the tableland or planalto proper.

The Serra do Mar, notched and pinnacled in the states of Rio de Janeiro and São Paulo, declines to the southward, and in Santa Catharina retains more of the character of the warped surface of mature relief which appears to have been characteristic of the whole belt in an early stage of its development following the warping above noted. In eastern Paraná the summits of the Serra do Mar form a line of peaks and ridges rising well above the eastern portion of the tableland



FIG. 28.—Crests of the Serra do Mar seen from the west on the tableland near Curitiba, Paraná.

or of the locally baselevelled tracts developed between the more resistant members of the tableland. The annexed diagram of the mountain crests as seen rising above the lowland east of Curitiba is typical of the region for many leagues northward into the state of São Paulo.

Isolated summits in this region rise somewhat above the level of the trap plateau. It is probable that in the late Mesozoic baselevelling of the region the granitic bosses and some of the gneissic areas were not reduced to the general level. On the north the lofty Serra da Mantiqueira culminating in Mt. Itatiaia nearly 10,000 feet in elevation, warrants this statement.

The slope from the crest of the Serra do Mar to the sea is generally steep. It is deeply ravined by short streams. The interstream areas form sharp spurs which in some portions of the slope are deeply dissected, standing out as isolated peaks and mountain blocks as on the south side of the harbor of Rio de Janeiro. The immediate descent to the sea is often so precipitous and the relief so high that where the geological structure is permissive of the hypothesis down-faulting on the ocean side has been advocated as by Dr. Derby as a factor in the production of the topography.

This deeply dissected slope has been depressed beneath sea-level since its dissection arrived at an advanced stage. The submerged valleys form harbors and reentrants such as those of Rio de Janeiro, Santos, Itajahy, São Francisco, and Florianopolis.<sup>1</sup> Since this depression in relation to sea-level took place, a slight uplift of about ten feet (3 meters) has occurred, raising up in the form of a platform about bay shores a recent deposit of littoral sands,

<sup>1</sup> The frequent repetition of the circumlocutions one is obliged to employ in expressing concisely the fact of our ignorance as to whether the land has sunk or the sea-surface risen when reference is made to a change of level of land and sea becomes intolerable in writing at length of such matters. Suess's terminology partially avoids the embarrassment but does not provide a name for a change of level of land and sea. The French term *denivellement*, a variation of level, suggests the use in English of its natural equivalent *delevelling* in analogy with *baselevelling*. A positive *delevelling* thus becomes a depression of the land in relation to the sea-level, and a negative *delevelling* an apparent elevation of the land in relation to the surface of the sea.

which also surround former rocky islets and unite them to the mainland.

Off the coast from the entrance of Rio Harbor southwestward to and beyond Laguna, low rocky islets of granite or gneiss reveal the continuation of the dissected slope of the Serra beneath the sea. These islands are of small size and mostly uninhabited except by occasional fishermen or as they may be the site of a lighthouse. Navigation between them is dangerous because of the fogs at certain seasons of the year and for the reason that lesser islets, or rocks which just reach the surface of the sea, are not wanting.

These off-shore islands are frequently partly surrounded by a platform of rock rising a few feet above sea-level. These benches correspond to the elevated strips about the bays and probably indicate the extent to which the subaerial upper portion of the island was reduced by weathering and the attack of the sea above the level of these platforms during the episode of maximum depression.

Bordering the inner shore of the bay of Paranagua, there are remnants of siliceous sands of presumably Tertiary date which appear to have been deposited within the dissected slope of the Serra do Mar, showing that the basal portion of the coastal slope was well dissected before the close of the Tertiary periods.

Professor Hartt found evidence at various points along the coast that an elevation or negative delevelling had recently taken place. Whether the coast from Rio de Janeiro southward is now undergoing a slow delevelling or not I could not ascertain. Faint traces of an old beach not now reached at high tide near Paranagua favors the idea of a recent elevation there.

The hypothesis above advanced of the warping up of the south Brazilian plateau with the axis of curvature along the Serra do Mar belt and the reference of the now dissected surface of a former peneplain to a Cretaceous date is based upon the fact that in the region of Bahia the Cretaceous strata extend far inland. It is thought that similar conditions prevailed on the south during a stage in the evolution of the present topography, that with the negative delevelling and the development of a steep slope to the sea and a gentle slope towards the interior the Cretaceous strata were denuded in early Tertiary time. The Tertiary basin in the valley of the Parahyba between the Serra do Mar and the Serra da Mantiqueira is taken as evidence of uplift and dissection of the Cretaceous peneplain prior to the deposition of the Tertiary fresh-water beds. The definite determination of the date of the Tertiary deposits would fix the limits of time to be

placed upon the epoch of dissection. (Branner, 1906, p. 283. A. S. Woodward, 1898, p. 63-75). Some warping of the surface has apparently taken place since the Tertiary beds were deposited.

At the northern limits of the region under discussion the Serra da Mantiqueira rises as a long lofty monadnock range in the Pre-Devonian terrane. The western slope of the crest of this gneissic mass subtends the surface of contact of the Permian of São Paulo upon the same ancient rocks. It therefore appears probable that in the Serra da Mantiqueira we have a remnant of the Permian floor east of the present line of outcrop of those strata.

Between the Serra do Mar and the escarpment formed by the westward dipping Devonian sandstone cuesta<sup>1</sup> there is a high level tract belonging to the planalto or tableland. On the South in the headwater region of the Iguassú about Curytiba it is essentially a peneplain and swamps of great extent exist locally. But in south-eastern São Paulo an Atlantic stream, the Rio Ribeira de Iguape, has breached the Serra do Mar and gnawed a deep ravine with its headwaters pushed against the crystalline Serra da Paranapiacaba for a watershed. The situation of this stream, the single example of any size to push its headwaters past the Serra do Mar and drain the planalto, in the great concave arc formed by the Paranapiacaba and the Devonian sandstone cuesta is evidently an effect of the Devonian sandstone ridge. The almost level crest of this Serra indicates the approximate level of the Cretaceous peneplain up to which level the plateau was filled with rocks before the present valleys and widened out lowlands of the planalto were excavated. Under these conditions the Devonian sandstones must have extended much to the eastward, possibly to the Serra do Mar crest. In the dissection of the country east of the present retreatal escarpment of the Devonian sandstones the Rio Ribeira de Iguape, protected from capture by the westward flowing streams, has worked backward following the shifting of the watershed formed by the retreating cuesta until its headwaters are in a position almost to capture the Rio Yapo and the uppermost Iguassú. (See map, Fig. 7, p. 43.) The short course and steep gradient of the river have enabled it to cut its present profound ravine. A similar history probably is true of the Rio Tuberão which in southeastern Santa Catharina has excavated its valley across the granitic terrane,

<sup>1</sup> The term *cuesta* used in a technical sense in North American writings on geomorphology for obvious reasons is not adoptable in Portuguese. "Costa do outeiro" misses the point in the English use of the Spanish name *cuesta*. Serra monoclina expresses in structural terms the essential characteristic of a *cuesta*.

corresponding there geologically to the Serra do Mar, and which has its watershed in the lofty crest of the Triassic escarpment on the west of the Permian belt of coal-bearing shales.<sup>1</sup> The Ypiranga, an affluent of the Bay of Paranagua, is apparently in the act of tapping the westward sloping surface of the planalto back of the Serra do Mar.

According to Drs. Derby and Euzebio P. de Oliveira the Permian sandstone overlaps the Devonian shales at places in Paraná and rises towards the crest of the Serra as at Vilha Vehla, a point of deeply disintegrated rocks southeast of Ponta Grossa, the name Vilha Vehla being applied in the same sense that "Rock City" is employed in North America. This ridge dies out northward in São Paulo and southwards in Paraná so that in Santa Catharina the geologically higher escarpment of the trap plateau on the south comes in as the first range inside the coastal mountain belt.

The relatively even sky-line of the Devonian cuesta forms a striking feature in the treeless landscapes for many miles in Paraná. The summit attains elevations exceeding 3,000 feet and approaches the level of the hypothetical Cretaceous peneplain out of the nearly level surface of which the lowlands between the ridges and plateaus of the planalto have been sculptured by Tertiary and more recent erosion. In northern Paraná and southern São Paulo the topographic relief becomes complicated by the erosion of longitudinal valleys and by the association of ridges developed on the lower Permian sandstones which succeed on the west of the Devonian outcrop. The streams in this district also have cut deep gorges across these ridges apparently along lines of drainage inherited from the time when they flowed on the Cretaceous peneplain. Such appears to be the origin of the defile in the massive sandstones through which the Yapo flows in the country northwest from Castro to Tibagy. At Joachim Murinho Station the railway follows a broad gap in the sandstones which appears to have been once occupied by a river much larger than the present stream. The escarpment of the Devonian here becomes very irregular by reason of dissection. The steep sandstone cliffs form precipices overlooking lowlands excavated to the level of the crystalline rock-floor as at Pirahy. A characteristic view is to be had from Fabio Rego Station looking towards the cliffs of the Serra Morumgaba surmounted by the Morro do Chapeo.

<sup>1</sup> For some account of the Ribeira de Iguape with maps and plans see a report entitled *Exploração do Rio Ribeira de Iguape*. Comm. Geog. e Geol. de S. Paulo, 1908.

The Devonian shales in central eastern Paraná give rise to a longitudinal valley but the non-resistant character of these rocks is locally counteracted by intrusions of diabase. The western side of this longitudinal valley, where it is developed, is formed by sandstones and conglomerates of the basal Permian. Ponta Grossa stands on the western side of this valley.

The sandstone and conglomeratic members of the Permian form an irregular grouping of uplands separated by river valleys. The level at which the hilltops stand, intermediate between that of the lowlands and the trap plateau and the Devonian cuesta probably indicates an intermediate stand of the land, the date of which is difficult to determine. The valleys of such rivers as the Tieté in São Paulo certainly have been excavated since the Tertiary deposits which underlie the city of that name. It seems highly probable therefore that the uplands in the Permian tracts antedate not only these Tertiary deposits but also the erosion of the depressions in which the beds were accumulated. The date of the evanescent peneplain with which the summits of the upland areas accord must be placed therefore in early Tertiary time.

The westward flowing drainage of the planalto gives rise to the dissection of the Permian terrane by long westward aligned valleys such as those of the Paranapanema and the Rio Negro, but the tributaries of the latter river including such large streams as the Tibagy flow obliquely across the trend of the Permian belt on courses expressing the resolution of the double control of the westward dip of the formation on the one hand and of the slope towards the master stream developed by concentration of the drainage on the other. The Rio Negro displays a rectangular adjustment of its course to the strike and dip of the Permian strata.

In the latitude of Curitiba there is traceable westward from the vicinity of that city a divide between the waters which drain northward into the Paranapanema and southward into the Rio Iguassú. This watershed includes the Serrinha, passes south of the towns of Palmeira and Iraty and thence joins on the west the trap escarpment known as the Serra da Esperança. The great extent of the drainage basin of the Rio Paranapanema as compared with that of the combined Iguassú and Rio Negro in the Permian terrane is apparently a consequence of the antilinal axis, which, normal to the arc of the outcrops in eastern Paraná and southern São Paulo, caused the Palaeozoic beds along this east-west line to stand relatively high and erode more rapidly. As a result of this distribution of the drainage

the headwaters of the Rio Paranapanema drain almost entirely the western slopes of the Devonian beds, as does the Ribeira de Iguape the crystalline terrane on the east of the Devonian sandstones.

The Permian tract is bounded on the west by the Triassic escarpment of sandstones crowned by trap sheets. The westward dip of the formation combined with the flow of the streams in that general direction has caused the trap to retreat far to the west along the axis of the main drainage lines, such as that of the Paranapanema and the Iguassú. In the western part of the south Brazilian states of São Paulo, Paraná, and Santa Catharina the rivers flow over the trap sheets whose resistance to erosion holds up to their local baselevel the entire drainage area of the planalto. The Rio Paraná on the confines of Brazil and Uruguay is gnawing back the southern edge of the trap sheets. Below the cascades and falls the river joins the drowned valleys of the La Plata system.

The rate at which the falls of the Paraná and Iguassú are receding has not I believe been determined. But it is evident that the rivers have cut back from the southern edge of the trap sheets since the land had something like its present elevation above the sea. If the land at the confluence of the Iguassú and the Paraná had been as long above sea-level as it has in the upper valley of the Iguassú, where the trap has been swept away over a large tract of the Permian, it is inconceivable that the youthful characteristic of falls and cascades should still persist. We are therefore compelled to conclude that the country immediately adjacent to the Paraná and Paraguay rivers has recently been uplifted in relation to the sea. As on the south of the trappean country in Banda Oriental there are marine Tertiary beds now above sea-level (Darwin, 1846, p. 1-3) and as along the coast of Brazil from north of Rio de Janeiro to the Amazon (Derby, 1907, p. 218-237) there are evidences of uplift since the Tertiary beds were there laid down, it seems a valid hypothesis that the excavation of the Paraná channel in the traps began in later Tertiary time through an uplift of the whole planalto of Brazil.

The upper courses of small streams in eastern São Paulo and northern Paraná generally flow in narrow gorges so recently cut that many side streams particularly of the wet-weather type enter by a fall over the brink of the gorge. Without a thorough understanding of the local baselevels of the Paraná system it seems out of the question to infer the cause of this revived stream-action.

A remarkable example of one of these streams is the Rio Itararé flowing north into the Paranapanema along the boundary between

the states of Paraná and São Paulo. Near the town of São Pedro de Itararé at the railway bridge this river flows in a channel which at one point in its cross-section is not more than three feet wide.

The channel lies in the white Devonian sandstones which present no great variation from layer to layer offering opportunity for the



FIG. 29.— Map of the Parahyba and Tieté rivers in São Paulo (After H. Williams).

selective solution which in limestone countries often produce similar gorges. The bottom of this gorge is said to be between 62 and 63 meters below the railroad bridge.

At one point west of the railway bridge there is a natural bridge of the sandstone which evidently points to the origin of this gorge as an underground stream.

It remains to note the curious course of the Parahyba in relation to the headwaters of the Rio Tieté in eastern São Paulo. The annexed map, traced from that of São Paulo by Mr. Horatio Williams, late of the São Paulo Geographical and Geological Commission, sets forth the pattern of the streams. (Fig. 29.)

It will be noted that the upper course of the Rio Parahyba under the name Parahytinga follows a southwest course to the great bend at Guarerema whence the course is northeastward to the sea beyond the limits of the map. These courses are in essential adjustment to the structure of the underlying Pre-Devonian rocks but the basin of the river below the great bend is largely formed by the Tertiary non-marine beds before mentioned. The great bend is made by a transverse gorge cut through the Pre-Devonian series which rise a few hundred feet above the riverplain. It is therefore to be presumed that the course of the river at this point is inherited from a former course which lay at the level of the intervening hill-tops. This earlier

stage of the river presumably was developed on the surface of the Tertiary beds.

The divide between the Tieté at Mogy das Cruzes and the great bend is occupied by rock-hills of low relief rising about 200 feet above the weakly developed drainage lines of the district. The natural course of the Parahytinga would appear to be westward into confluence with the Rio Tieté of which it may be regarded as a beheaded portion, captured by the Rio Parahyba, which, pushing its head southwestwards along the easily eroded Tertiary beds, diverted the stream before erosion had swept away the Tertiary beds between the Parahyba basin and that of the Tertiary beds at São Paulo.

*The Pleistocene and Recent Formations.*—The discrimination of the Post-Tertiary changes in extra-glacial regions into Pleistocene and Recent is attended with difficulties. In Brazil the surface deposits are prevailingly residual clays or clays, sands, and pebble beds derived from the secular washing and transportation of weathered Pre-Pleistocene formations. Great differences exist as to the depth of the decayed rock even on the same formation. Where the rainfall is heavy at certain seasons of the year, the slope of the ground steep, and the run-off effective, the decayed materials are removed nearly as fast as their disintegration or decomposition is accomplished and thus nearly fresh rock occurs at the surface. I was frequently surprised in the valleys of the Rio Negro and the Rio Tuberão by the apparent freshness of carbonaceous shales at a depth of a few centimeters below the surface but in these situations erosion has been and still is actively in progress.

The new cuts of the railway in construction from Bury in São Paulo via São Pedro de Itararé and Jaguarihyva to Ponta Grossa in Paraná gave at the time of my visit an unusual opportunity to see many excavations in the mantle rock. Along the banks of the Rio Jaguaricatu in the Permian tillite beds these cuttings were often from 5 to 10 meters deep. At these depths most of the pebbles were still undecomposed.

At numerous localities along the railway line across the mature topography of southern São Paulo and Paraná the rounded swells between streams display traces of ancient gravel beds usually with concave lower limits as if occupying old stream channels long since abandoned. The same phenomenon is observable in a pronounced manner where the railway from Ponta Grossa to Serrinha Station in Paraná skirts the lower westward slopes of the sandstones of the Devonian cuesta. In all these cases the history of the surface appears

to be as follows:—The streams and wet-weather wash concentrate pebbles in their beds leaving the interstream swells or rounded ridges comparatively free from coarse material. The finer decomposed material of the interstream areas becomes more readily eroded than the coarse débris in the stream channels and erosion proceeds more rapidly

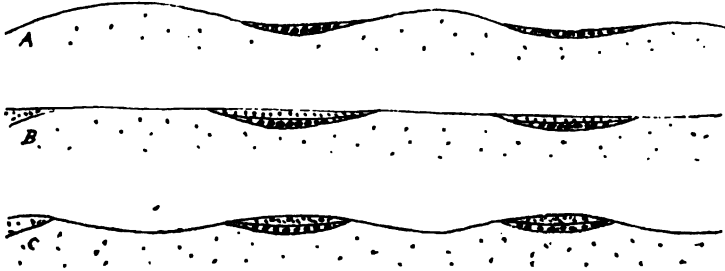


FIG. 30.— Showing supposed stages, A. B. C., in the concentration of gravels in creases and the deposits on ridges between creases on the dip-slope of pebbly sandstone beds.

along them so that they become depressions between the old deposits. Concentration of coarse débris begins again in the now new well-defined creases which carry off the rainfall. So far as my observations go there have been but two cycles of such gravel accumulation, an ancient one and that now actually taking place. If the process depends solely upon the relative resistance to erosion of the gravel-bearing creases and the gravel-free ridges between streams the change may well be automatic under a constant rainfall during the period of alteration. After one such shift the interstream areas become partly gravel-capped and an equilibrium is established which at first did not exist. Thus the dual character of the phenomenon in Brazil may be due to this limitation inherent in the nature of the process, even with a variable rainfall.

In the case of the deposits of this nature on the Serrinha near Tamanduá in Paraná the ancient gravels occur in abundance and appear to exceed in thickness those of the present wet-weathered channels. That these older gravels in this climate are as old as the Tertiary period seems to me improbable since under the conditions of exposure to weathering they must have broken down. At best they might be Pliocene, but if it is admitted that the glacial epochs of the Pleistocene were signalized in south Brazil by a heavier rainfall than that now prevailing it is probable that the older gravels represent one:

of the older glacial episodes comparable to that of the Columbia gravels south of the terminal moraine on the Atlantic slope of North America.

A short distance west by south from Araucaria Station in Paraná near kilometer post 26 on the railroad from Serrinha to Curitiba I

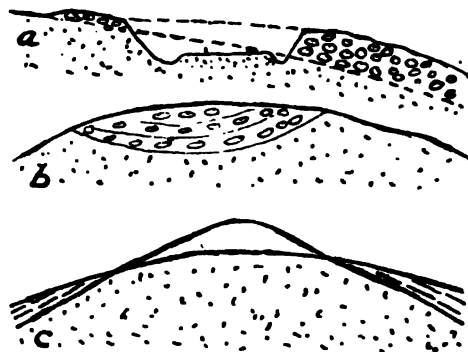


FIG. 31.—a, cross-section of the road cut in which the upper dotted line gives the present slope, the lower one, the slope on which the old gravels were deposited; b, cross-section of the spur on right of railway; c, theoretical restoration of both sides of a gravel-bearing hill, the upper portion being removed in the segregation of the gravels.

noted, in a railway cut through a spur, evidence that these old gravels were deposited on a steeper slope than that of the modern neighboring creases. The relations of the ancient and modern profiles are shown in the annexed diagrams. The gravel bed was evidently deposited in a crease, the axis of which corresponds with that of the present spur as above explained. From the consideration of such a case it becomes evident that the existing smoothened contour of the ground is due to the removal of the crests of old spurs and ridges and the accumulation of the coarse detritus near the bases of the slopes, and thus that a topography of sharper outlines preceded the present cycle. This means a considerable lowering of the elevations of the region since the old gravels were deposited and confirms the idea of an early Pleistocene date at least for the age of these deposits.

On the baselevelled plain about Curitiba where rounded ridges of mature dissection modified by deep weathering are interspersed between shallow water courses the cuts show many signs of the gentle processes of solution by which the surficial rocks have been removed. In one such cut near the Meteorological Station in the west bank of

a small valley there was exposed in 1908 in the road the section diagrammatically shown in Fig. 32.

A quartz vein about 2 inches (5 cm.) thick dipping E.  $30^\circ$  in a section of decomposed schists had given rise to a sheet of quartz fragments at the base of the residual structureless surface deposits

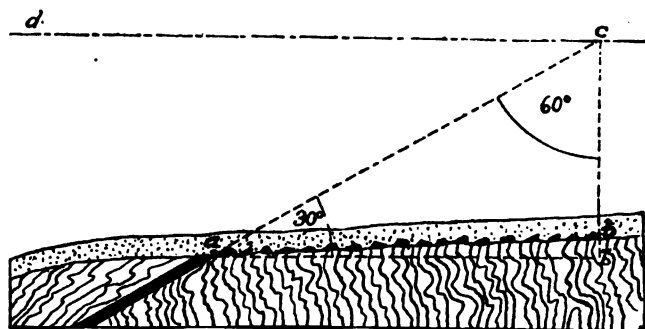


FIG. 32.— Train of residual quartz fragments derived from a vein during the weathering and ablation of the crystalline schists. Near Curitiba, Paraná. a-b, a distance of 50 feet from the outcrop of the quartz vein to the limit of fragments; c-d, the supposed surface at which the vein outcropped.

traceable fully 50 feet (15.2 M.) to the westward on the gently inclined surface of the schists. The original aerial extension of the quartz vein from the data here presented must have been at a height of 29.5 feet (8.1 M.) above the present surface as may be readily determined by a calculation of the right angle triangle. The two to three feet of overlying structureless residual clay may or may not represent the breaking down of about thirty feet (9.15 M.) of rock above the present surface of the schists. In either case solution by percolating water has been the chief agency in denudation. If the removal of this thickness of rock went on at the average rate for such drainage areas as have been studied — a rate as great as one foot in 3,000 years, the time represented in this case for the lowering of the quartz fragments is approximately 88,500 years, a period which takes us back according to the newer<sup>1</sup> estimates to the close of the last glacial epoch in North America. To this estimate should be added the time for the accumulation of the overlying clays whose superposition on the quartz

<sup>1</sup> The most recent studies of the retreat of the Wisconsin ice-sheet and the glacial lakes and marine phenomena which succeeded the glacial retreat demand from 5 to 10 times the 10,000 years of earlier estimates.

fragments seems to point to some shifting of the residual clays. The definite termination of the band of quartz fragments at a distance of a few yards from the outcrop of the vein means that this old surface was at the beginning of the period of weathering swept clean of quartz fragments, either because of a steeper slope than that now found at the locality or by reason of a more powerful run off. This latter possibility is consonant with the hypothesis of a heavier rainfall during the Pleistocene, however much the above attempt to calculate the time employed may vary from the true duration of Post-Tertiary epoch.

*River Terraces.*—Along several of the larger rivers of south Brazil there are terraces of sand and gravel evidently remnants of a former aggraded floor of their valleys. These deposits date back presumably to the Pleistocene with its greater rainfall.

For examples, a terrace occurs in the Rio Iguassú between kilometer posts 47 and 48 along the railway between Araucaria and Balsa nova Stations in Paraná; a terrace also occurs north of Balsa nova at km. post 59. Other fragments of this terrace occur along the river further up the valley.

The Rio Capivary in Paraná between Lago and Palmeira exhibits a terraced plain.

In southern São Paulo a gravel terrace of old river cherts is crossed by the railway between Herval Station and Engenheiro Hermilho Station.

These gravelly terraces, apparently of the same epoch as the Tamanduá gravels on the hillsides, are probably in their later stages derived from the washing down and gulying of these deposits. Owing to the nature of river changes it is improbable that the formation of the terraces by reexcavation of the old valley floors should have been synchronous throughout the area under discussion.

Numerous cuttings along the railways in São Paulo and Paraná show that the clayey deposits there, varying but little from the *terra roxa* and the *terra vermehlo*, are not strictly residual but are rather transported or shifted, however much they have decayed in their present sites. Dr. Derby expressed the opinion that the red earth, of which an excellent exposure was examined at the railway station in São Pedro de Itararé on the confines of São Paulo and Paraná, was an equivalent of the loess of other regions.

The thickness of these deposits varies greatly. Many sections were seen varying from six to ten feet, but in many the bottom was not exposed. The material appears to be developed particularly

along the lower slopes of the hills as if washed down by rains during the wet season. Much dust is blown about by the winds in the dry season and doubtless an eolian origin may be attributed to some of the particles.

The relations of the red earths to the underlying pebble beds indicate pretty clearly the order of magnitude of the powers of the rainfall in the immediate past and the changing climatic conditions, a heavy rainfall with a strong run-off followed by a marked weakening in this agency. Wind action if registered in the loess-like red earth hardly can be called upon in the case of the gravels in old creases. Lag-gravels are typically developed upon wind-swept plains; besides glyptoliths or sand-carved pebbles are not here forth-coming; farther north in Brazil Dr. Lisboa has found them.

These deposits are related to each other in the range of dynamic force concerned as are the Pleistocene glacial gravels to the Post-glacial alluvial deposits of many North American sections. Hence the probability that the gravels represent the Pleistocene. From an excellent exposure in Paraná at Tamanduá Station I propose the name Tamanduá (anteater) beds for the gravels. As for the overlying shifted reddish earths whether *terra roxa* or not, they form a group of surficial deposits blending in places with residual clays *in situ* and do not so readily take a formation name.

In railway cuts in the white sandstones between São Pedro de Itararé and Fabio Rego the red earth rests on the eroded surface of the white sandstones. The sharpness of the contact between the two and the absence of red coloring in the sandstones proves the shifting of the superficial deposit with its coloring matter. The development of the red oxide of iron would seem here to have antedated the transportation of the material otherwise the red matter seemingly should have been carried downward into the porous sandstones.

In the winter season of drought the red earth dries and cracks. These cracks on the surface of newly cut banks by the railway stations often form a hexagonal network. Similar cracks form over the surface of the campo. As leaves, sticks, and insects peculiar to the existing flora and fauna readily fall into these cracks to some depth in the clays, it is obvious that by the closing and opening of these cracks under the changing seasons any contemporaneous fossils they may be found to contain must be carefully discriminated from post-depositional entries.

Canga is a superficial segregation of oxide of iron or limonite in various geological positions. On the road from Ponta Grossa to Conchas in

Paraná it forms crusts in the surficial decomposed portion of the bed rock. In a railway cut on the banks of the Iguassú near Serrinha Station in Paraná the outer portion of the Carboniferous rocks is crusted with canga and this vein-like material there occurred in joints. The segregation of canga by percolating water seems mainly to be ancient; it may be older Pleistocene or still older, and probably is not peculiar to any one episode of the modern geological history of the region.

The canga in some localities appears to have been broken up and transported, now occurring as rubble in the red surface deposits as between São Pedro de Itararé and Fabio Rego. In this case the canga must have been segregated prior to the transported red earth, and if the red deposit be assigned a Pleistocene date the canga may be referred to the Tertiary.

The decomposed state of the rocks in Brazil was early recognized and correctly described by José Bonifacio de Andrada e Silva and Martim Francisco Ribeiro de Andrada in an account of a mineralogical journey from Santos to the tableland made in 1820. This article is reprinted in Ferreira's *Diccionario geografico das Minas do Brazil*. Rio de Janeiro, 1885, p. 341, 342.

*Weather-blocks.*—The weathering of the granites along the coastal slope of the Serra do Mar has led to the production of thousands of rounded weather-blocks which are particularly evident at the present sea-level and just above within the zone of wave action, those above the present sea-level having had the fine material between them removed in part at a time when the land stood a few feet lower than it now does. Abundant examples are to be seen about the shores of Rio Harbor. The illustration, Plate 2, is from a photograph of a group of blocks on the shore of São Francisco Harbor in Santa Catharina. In Madureira, a suburb of Rio de Janeiro, near Cascadura Station there is fine large block said to be movable (*pedra movediça*) poised high up on a weathered tower of granite. The famous Furnas de Agassiz at Tijuco in the Serra near Rio de Janeiro is another group of weather-blocks, the most imposing to be seen anywhere in south Brazil.

It remains to note certain rock benches and the uplifted fringing coastal plain to be seen along the shores from Rio de Janeiro to near Laguna on the south.

From observations made about São Francisco Bay in latitude 26° S. I suspect that there exists along this coast an old bench of marine erosion 150 or more feet above the present sea-level. Numerous rock

islands along the coast at variable distances from the shore rise to nearly this height and about São Francisco Bay well in back of the town there are low foot hills separated by valleys from the base of the Serra and from each other, and similar hills confront the somewhat higher ones at the south side of the entrance. Presumably this



FIG. 33.— Terrace about islet in the sea north of Laguna, Sta. Catharina.

dissected rock bench is of very ancient date, early Pleistocene or Tertiary.

A more recent set of rock benches form narrow platforms about many rock islands along this same extent of coast apparently standing from eight to ten feet above sea-level. They agree closely in level with the alluvial plains bordering the bays. Figure 33 gives the outline of such a terrace skirting the base of a small rocky islet north of Laguna as seen from a steamer. Hartt (1870) has given abundant evidence of a recent uplift of the coast to this height. This change of level is seemingly very recent.

Between the first described signs of a very ancient bench, and this recent uplift must be interpolated an episode of subsidence carrying the sea into the valleys at the base of the Serra do Mar. The harbors, great and small, are due to this change of level. The filling up of the harbors and river channels and the building of an underwater deposit makes an estimate of the depth of this depression too small but as the harbor at Rio de Janeiro has a maximum depth of 30 M. (Hartt, 1870, p. 7) the sinking must have been equal to this depth plus the amount of the recent elevation.

On the flats east of Paranagua there is a well-defined low beach ridge covered with dead shells of *Ostrea* and a smaller gibbous lamelli-branch at an elevation of eight or ten feet above sea-level and separated from the shore of the bay by two flats at slightly different levels. The shells are not worn; some of them have both valves in position. The situation of the deposit and the mode of occurrence of the shells is very different from that of the accumulation of shells left by aborigines on neighboring sandy deposits.

*Geographic Control of Human Occupation.*— The effect of the several geographic features above outlined on the human occupation of

south Brazil are more or less patent to every visitor. The dissection of the coastal slope and the depression of the resulting Serra do Mar has given rise to commodious harbors so uniformly wanting because of the unlike geological structure and form on the west coast of South America. But the Serra do Mar renders ingress to the country exceedingly difficult and possible for roads and railways only along certain routes. Back of the Serra do Mar for the most part the lands slope toward the interior of the continent, and the large rivers, navigable by small boats, serve only with ease to carry commerce into the interior. The transportation to the coastal border of the plateau is everywhere upgrade making the export of the products of plantations and the forest more costly than the importation of foreign goods, an item of cost which is offset on the inward journey by the necessity of ascending the Serra do Mar, and, to reach the trap plateaus, of surmounting the Triassic escarpment. Transportation is naturally slow to develop, except where peculiar conditions, such as give rise to the rich coffee-fields of São Paulo, have repaid the construction of railways.

The recently uplifted plains of alluvium bordering the harbors afford the sites for the first settlement of the sea-coast. The variable relief of the dissected front of the Serra do Mar furnishes stations for residence at altitudes great enough for Europeans, whose affairs require their daily presence in the federal capital, to escape the languishing effects of a continuous abode in the hot zone at sea-level, but the way to these retreats calls for special and costly methods of transportation, as in the case of the route to Petropolis. Owing to the mountainous relief of the coastal slope of the Serra do Mar and the luxurious growth of tropical vegetation the inhabitants enjoy outlooks unsurpassed in any land. As a scenic route for the traveller the railway journey from Paranagua to the summit of the Serra through the defile of the Ypiranga is surprisingly pleasant, and at many points exciting.

The contrast between this region and the surface of the plateau is striking. The tableland is the seat of production. Variations in the geological character of the surface modified by altitude and rainfall come sharply into play. In northern São Paulo and adjoining parts of Minas Geraes the soils known as *terra roza* and *terra vermehlo* developed by decomposition of the trap sheets which invade the Permian terrane afford under the peculiar conditions of rainfall there existing the richest coffee-fields in the world. Farther south the Devonian and Carboniferous sandstones present less favorable conditions. Open campos or prairies characterize much of the region underlain by Palaeozoic strata.

Much has been said as to the origin of the treeless condition of this region. About Ponta Grossa in Paraná the persistence of the elements of the forest along the brooks and rivulets and near the water courses would seem to point to the oft repeated supposition of a diminished rainfall following the glacial period as the probable cause. In my notes on the surface deposits I have presented some reason for thinking that traces of such a change in the rainfall and run-off are observable.

In Paraná and Santa Catharina farming and cattle raising find suitable conditions and here the influx of European settlers from Germany, Poland, and in Rio Grande do Sul from Italy, has under the more temperate climate of the upland wrought commensurate changes in the appearance of the country.

Mention has already been made of the harborage to lingering remnants of hostile natives which the Triassic trap escarpment affords. Farther in the interior larger bodies of aborigines favored by the unnavigable rivers made inaccessible from their lower courses by reason of the numerous falls over the trap sheets maintain to a large degree the primitive state of the Brazilian highland.

#### VIII. NOTE ON THE CHANGES OF LEVEL OF THE COAST OF SOUTHERN CHILE.

For more than seventy years Darwin's raised beaches and terraces of the west coast of South America have been generally regarded by English-speaking geologists as typical examples of a relative change of level of land and sea. Sir Charles Lyell by embodying the observations and conclusions of Darwin in his classic *Principles of geology* gave wide distribution to the views of Darwin concerning the magnitude and extent of the supposed recent elevation of the west coast of South America. A dissent from the views of the justly celebrated naturalist of the "Beagle" was scarcely heard in geological circles until in 1885, when Edouard Suess brought out *Das Antlitz der Erde*, in which work he sought to show by testimony mainly that of observers of the Chilean coast since Darwin's voyage, that no noteworthy elevation of this coast in recent times had taken place. Upon the publication of the French translation of Suess's great work, *La Face de la Terre*, the writer (J. B. Woodworth, 1898, p. 803-806) in a review expressed a disbelief in the sufficiency of the evidence brought against Darwin's observations and conclusions. In fact, I went to Chile rather for the purpose of studying the nature of the movements, whether by frac-

ture and faulting or otherwise, which must have attended this supposed elevation, than to confirm or refute any conclusion as to the elevation of the coast at a time so recent as that embraced within the period of elevation of beaches, so well established in the Champlain or Hoche-lagan marine district of northeastern North America. The following notes and conclusions thus have the force of being made with a pre-

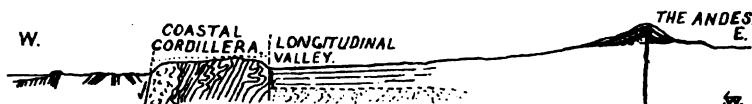


FIG. 34.— Diagrammatic cross-section of southern Chile west of the Andes. Based on Pissis and personal observation in the longitudinal valley and Coastal Cordillera.

conceived opinion quite opposite in most respects to the judgment which in the sequel I was obliged to make. But the geological structure bearing on changes of level should be first set forth.

The geological structure of Chile south of Valparaiso is in its broad outlines readily grasped in such a rapid reconnaissance as I had the opportunity to make. The main facts were clearly outlined by Pissis (1875) from whose work and my own observations the following brief introduction will serve to make clear the relations of the Coastal Cordillera with its frequent earthquakes, and the chain of the Andes lying back from the coast.

In south Chile for a great distance north and south there are three well-defined topographic and structural zones, viz.: — the Andesian folded chain with volcanic vents, the Longitudinal Valley confronting the chain on the west, and the Coastal Cordillera forming the coast. These three differently constituted areas are shown diagrammatically in the subjoined cross-section, Fig. 34.

The formations which enter into this section were roughly determined by Darwin (1891) as follows: —

Darwin's scheme of geological formations in Chile.  
(Compiled from "Geological observations.")

|                                                      |                                                                                                                                                                                                                                                                |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Newer Tertiary, including the basin-plains of Chile. | Superficial saliferous deposits of Iquique. Salt and nitrite of soda, 3,000 ft. above sea-level.<br>Beds of gravel, red sandy clay; lava, pumice beds, overlying calcareous tufa.                                                                              |
| Concepcion formation.                                | Sandstones with lignites, silicified wood, and "concretions" carrying marine shells. Eruptions.                                                                                                                                                                |
| Upper Cretaceous?                                    | Tuffs and submarine lava of Uspallata section; conglomerates of valley of Tenuyan.<br>Upheaval in central Chile forming Cumbre and other ranges.                                                                                                               |
| Cretaceo-Oolitic; Gypseous formation.                | Coarse conglomerates, siliceous sandstones, dark mudstones, limestone, pseudohornstones, tuffs, and vast beds of gypsum, with marine fossils and silicified trunks of fir-trees at Los Hornos. Eruptions of purplish claystone and greenstone porphyries, etc. |
| Metamorphic series.                                  | Metamorphic schists, plutonic rocks, and more or less altered claylate.                                                                                                                                                                                        |

The more recent work on the geology of Chile has been summarized by Mr. Lorenzo Sundt (1909, p. 37-44). According to this geologist, the sedimentary formations now recognized in Chile are as follows:—

## Geological formations of Chile, mainly from Sundt.

|                                         |                                                                                                                                                                    |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pleistocene.                            | Eolian and other deposits of Atacama on the north.<br>Glacial till and gravels in the south.                                                                       |
| Eocene.                                 | Conglomerates and sandstones.<br>Lignitic group of Coronel.                                                                                                        |
| Cretaceous.                             | Sandstones of Quiriquiña Island, and along the coast.<br>Conglomerates, sandstones, and black calcareous, fossiliferous shales of Coquimbo and the Pequeñas Range. |
| Jurassic.                               |                                                                                                                                                                    |
| Triassic                                | Not recognized.                                                                                                                                                    |
| Sub-Carboniferous or<br>Upper Devonian. | Fossiliferous beds at mouth of the Rio Choapa.                                                                                                                     |
| Devonian or older.                      | Metamorphic series; mica schists of Coastal Cordillera south of Caldera.                                                                                           |

The Andes consist of deformed, squeezed up, and dissected beds of the Tertiary and older rocks, with eruptives. The Longitudinal Valley comprises Tertiary and possibly older beds overlain by lavas and Pleistocene gravels the preglacial members of which series apparently dip gently westward until cut off by the eastern fault of the Coastal Cordillera. The Coastal Cordillera, made up of the metamorphic series and granite intrusions, is fringed by Cretaceous and Eocene deposits in faulted relations with the older terrane.

The Coastal Cordillera forms a long narrow tableland parallel to the coast with an elevation from 1,200 to 1,500 feet, the flattish upper surface of which is evidently a peneplain from which more recent beds

have been denuded. These beds appear to have been the same Cretaceous and Tertiary strata which occur in patches along the coast in dislocated positions. The borders of the Coastal Cordillera are determined by faults so that the Cordillera is itself a long relatively uplifted fault-block or "horst." Relative to it, the western side of the Longitudinal Valley on the east has sunk as has also the Pacific Ocean border on the west. It is along the fault-zone on the west, partly if not altogether, that the epicenters of great Chilean earthquakes mainly lie as was the case with that of Coquimbo in 1906, which destroyed Valparaiso and neighboring towns.

It follows from this structure of the west coast of South America throughout the greater part of Chile that the earthquakes which take place along the faulted edges of the Coastal Cordillera arise from the movements of this horst and are not directly connected with the folded chain of the Andes on the east. Accepting as I think we must the essential accuracy of Darwin's and Fitzroy's observations upon the elevation of the coast about Concepcion at the time of the earthquake of 1835, it does not follow, however, as Darwin thought, that the Andes were simultaneously elevated.

In the Valparaiso earthquake of 1906 Professor Steffen has found evidence of a local elevation amounting to half a meter on the western border of the Cordillera at that place; but it is a question whether the elevations which take place at the time of these earthquakes are permanent. At Concepcion it is the opinion that a subsidence follows the uplift of the coast. Nevertheless the horst stands as an indubitable block of evidence of uplift in relation to the ocean bottom and the Longitudinal Valley.

The date of beginning of the faults which bound the horst of the Coastal Cordillera is Post-Eocene and apparently late Tertiary. Whether movement has taken place in modern times along the fault on the east I am not able to say. The Pleistocene gravels at San Rosendo abut against the horst without signs of disturbance; and the rivers, such as the Bio Bio, Calle Calle, and Maule, have cut channels across it on their way to the sea from a superposed position. Neither the Rio Bio Bio nor the Calle Calle, through whose valleys I passed in traversing the width of the horst, display rapids such as might be due to recent uplift at a greater rate than that of the cutting power of these streams to maintain a free grade to the sea.

It seems most probable that the eastern fault bounding the Longitudinal Valley is of early Pleistocene or late Pliocene date, and that the present valley is due to erosion of the lavas and sediments *pari passu* with the cutting of the gorges.

If one reads Chapter X on the Plains and valleys of Chile in Darwin's Geological observations, he will find the author convincing himself that the sea rather than the rivers now coming out of the Andes is accountable for nearly every detail of the land form,—not only the passes in the mountains and the valleys sculptured in the mountain mass but also the plains of waterworn detritus particularly where rounded pebbles are found.

This statement tallies with the general belief of the school of geologists of the period in which Darwin formed his concepts. It was naturally easy for him to admit terraces of any origin and marine shells on the surface at lower levels along the coast of Chile as evidence of elevation when he had found to his own satisfaction that the sea had beaten against the high Andes where no recent marine shells are found. This much is necessary for the reader to understand in weighing the conclusions which may be presented concerning the elevation of the coast of Chile.

It is only just to Darwin, however, to show from his own writings how he abandoned the views he entertained concerning topographic signs of elevation on the coast of South America when in later years similar problems came to his attention in the British Islands.

Darwin (Francis Darwin, 1903, 2, p. 191) wrote Lyell in 1861,—  
 "I return Jameson's capital letter. I have no comments, except to say that he has removed all my difficulties, and that now and for evermore I give up and abominate Glen Roy and all its belongings. It certainly is a splendid case, and wonderful monument of the old ice period. . . . How many have blundered over those horrid shelves!"

Again in 1868, Darwin (Francis Darwin, 1903, 2, p. 211) wrote Croll,—  
 "I was formerly a great believer in the power of the sea in denudation, and this was perhaps natural, as most of my geological work was done near sea-coasts and on islands.

"But it is a consolation to me to reflect that as soon as I read Mr. Whittaker's paper on the escarpments of England, and Ramsay and Juke's papers, I gave up in my own mind the case; but I never realized the truth until reading your papers just received. How often have I speculated in vain on the origin of the valleys in the chalk platform round this place, but now all is clear." Still he clung to his interpretation of terraces and of shells on the surface in South America. As late as 1872, Darwin wrote Lyell (Francis Darwin, 1903, 2, p. 164-165),—  
 "It seems to me very cool in Agassiz to doubt the recent upheaval of Patagonia, without having visited any part of it; and he entirely misrepresents me in saying that I infer upheaval from the form of the land, as I trusted entirely to shells embedded and on the surface.

"It is simply monstrous to suppose that the terraces on a dead level for leagues along the coast, and miles in breadth, and covered with beds of stratified gravels 10 to 30 feet in thickness, are due to sub-aerial denudation."

Darwin seems here to have forgotten what he wrote on the shells embedded in a friable calcareous rock in the terraces of Coquimbo at a height of 250 feet. "Although I examined so many hundreds of miles of coast on the Pacific, as well as Atlantic side of the continent, I found no regular strata containing sea-shells of recent species, excepting at this place, and at a few points northward on the road to Guasco. This fact appears to me highly remarkable; for the explanation generally given by geologists, of the absence of stratified fossiliferous deposits of a given period, namely, that the surface then existed as dry land, is not here applicable; for we know from the shells strewed on the surface and embedded in loose sand or mould, that the land for thousands of miles along both coasts has been lately submerged." (1845, p. 344.)

The interpretation of the shells strewed on the surface and embedded in the loose sand or mould constitutes the essential difference between Darwin's hypothesis of their marine deposition and the theory that such surficial deposits pertain to the group of kitchen-midden.

My own observations of the coast of Chile were made about Corral and Valdivia in latitude 40° S., at Talcahuano and Concepcion, in latitude 35° 35' S., and with less scope about Valparaíso in latitude 33° S.

*The Coast at Corral and Valdivia.* Of Valdivia, Darwin (1891, p. 236) states "I did not observe any distinct proofs of recent elevation; but in a bed of very soft sandstone, forming a fringe-like plain, about sixty feet in height, round the hills of mica-slate, there are shells of *Mytilus*, *Crepidula*, *Solen*, *Novaculina*, and *Cytheraea*, too imperfect to be specifically recognized."

The plain or rather terrace which Darwin mentions extends from the open coast outside of Corral entrance (Plate 29), about the sides of the harbor of Corral and up the Valdivia River to the city of that name. It is well shown about the sides of Manzanera Island in the harbor of Corral (Plate 30), and is a distinct feature along the banks of the Valdivia River (Plate 31). It is a terrace of denudation sometimes cut in the soft Tertiary sandstones mentioned by Darwin, sometimes in conglomerates as at Corral, and sometimes in the schists. About Valdivia and Teja Island this terrace I estimated to be fifty-five feet above the sea-level and the same along the Rio Cruces Channel. The

same level holds for the seaward edge of the terrace on the south side of Corral entrance facing the open sea, where, however, the surface rises inwards towards the hills, being in part covered by deposits at the mouths of gullies. The terrace thus has the appearance of being a few feet higher on the coast than inland. At most, the terrace is a few rods in width and carries here and there a few houses. On the south side of Corral entrance near English Bay, there are drongs, or stacks of the schists standing up on the surface of the terrace, evidently sea-stacks left by marine erosion at about the sixty foot level. I saw none of these along the Valdivia River or inside of Corral Harbor. I have no doubt that this bench marks a stand of the sea when the coast stood relatively lower than now. Above this terrace the hills are sharply ravined by long continued sculpturing of the schists and no signs of beaches or wave action were found. The next higher plain is that of the summit of the Coastal Cordillera (Plate 29), which is undoubtedly an old peneplain of Tertiary or older date.

The lack of beach deposits or signs of modern occupation of the fifty to sixty foot terrace by the sea makes it necessary to place its origin in early Pleistocene or possible Pliocene times. It is long anterior to such beaches as occur about the shores of the Champlain or Hochelagan sea in northeastern North America.

South of Corral entrance near a group of houses I saw marine shells on the terrace in the sod but they were in such a situation as to render it altogether probable that they had no geological significance, being nothing more than refuse of the aborigines.

At Valdivia and Corral it seems to me demonstrable that there was in early Pleistocene or late Tertiary times a relatively lower stand of the land than now by about sixty feet during a period long enough for the river to widen out its valley on a rock-floor of schists and older Tertiary sediments in a disturbed position. Whether these Tertiary sediments occupy an old valley in the schists or owe their position to down-faulting I can not state from the observations which I made. Their disturbed attitude and the presence of cleavage in the conglomerates at Corral favors the view of infolding and down-faulting of the Tertiary beds in the schistose terrane. After this period of partial baselevelling the land rose about sixty feet relatively to the sea.

The presumption that the channel of the Valdivia River and the depression forming Corral Harbor have been excavated since the uplift of the terrace began is also an argument for the ancient date of the sixty foot terrace. The depths of water in the Valdivia River

and connecting channels vary from forty-eight to ninety feet and depths of seven and eight fathoms occur in the Rio Valdivia opposite the town. While glacial gravels and boulders not far inland as at Llanco Station show the presence of Pleistocene glaciers or glacio-natant waters, I noted no distinct signs of glacial erosion of the channels about Valdivia. It seems to me more probable, therefore, that these depths indicate a depression of the coast since the formation of the terraces rather than that they are due to glacial erosion independently of the sea-level.

Below the fifty-five to sixty foot level, I noticed a small terrace on Teja Island opposite Valdivia at a height about twenty-five feet above sea-level, but this was not elsewhere observed except possibly as noted below.

Along the coast south of Corral entrance near Palo Muerto Pt., there are several ancient sea-caves not now visited by the sea at high tide. Near them is a trace of a bench at about 22 feet. The mouths of these caves are not over ten feet above sea-level (Plate 33). The bottoms of the caves are covered with a fine dusty cave-earth which covers any pebble bed which may occur on their bottoms. One of the caves (Plate 33) had been at the time of my visit recently occupied by natives and a heap of shell refuse formed a considerable mound at the entrance. In the same vicinity at Morro Gonzales there is a natural bridge in the rock of the sixty foot terrace formed by a cave penetrating to a small ravine in the rear. In front of the caves at a few points where the coarse Tertiary conglomerate is developed there is a flat or bench, cut back across these rocks, whose surface is at least partly covered by high tide. It is evident that a slight relative rise has taken place removing the caves from the action of the sea, but while this may have been as much as ten feet it may not have been over five feet as the depth of cave-earth would seem to show. In embayments south of Corral entrance, there are old beach ridges the highest of which comes sharply against the ravined surface of the land behind it. The uppermost of these ridges agrees well with the level of the mouths of the caves and does not indicate a rise of more than ten feet and possibly not more than five feet above sea-level; but, as Suess has pointed out, on the west coast of South America beach ridges may be thrown up by seaquake waves or *tsunamis* above the normal marine limit and thus are to be taken with caution.

*At Talcahuano and Concepcion.* The literature concerning elevation about the Bay of Concepcion relates largely to the discussion

concerning the change of level accompanying the earthquake of 1835. As Darwin noted, little or no evidence of the elevation claimed by him and Fitzroy could be seen by a subsequent visitor. The Old Fort at Penco (Old Concepcion) is shown in Plate 4. The alleged evidence of elevation prior to this famous incident pertains largely to marine shells found on the hills about the Bay of Concepcion. Another feature which undoubtedly is the result of relative uplift of the land is the alluvial plain upon which the modern city of Concepcion stands.

Ulloa (1772, 2, p. 252-254) who visited Concepcion Bay as early as 1744 describes the occurrence of shell deposits from six to twelve feet and more in thickness within four or five leagues from the shore and also on the tops of hills fifty toises (320 feet) high. He mentions seeing one deposit at a height of twenty toises.

Darwin (1887, p. 310) speaks of "the vast number of sea-shells scattered over the land, up to a height of certainly 600, and I believe," he states, "of 1000 feet." He appears to have entertained no doubt that these shells were evidence of an elevation of a former sea-bottom to these heights as explaining the occurrence of the shells.

The shell deposits described by Ulloa in the plain about Concepcion, though I did not see them, presumably are in their natural site as they form a part of the tilted plain of the "Formation of sand and shells" described by Pissis. This plain at Concepcion I estimated by aneroid to be forty-five feet above sea-level. Westward towards Talcahuano there are successive lower levels, that at the golf links I made seventeen feet, and the next lower level adjacent to the bay of Concepcion about ten feet. The surface has been more or less modified by the blowing of sands by the winds. I saw several boulders in the upper dark stratified sands of the plain between Concepcion and Talcahuano along the railway cuts. One of these blocks was eighteen inches in diameter. These boulders were in an embedded position and would seem to demand floating ice for their transportation. It is to be presumed that the water-laid portions of the deposits are therefore of Pleistocene date.

Back of Concepcion the plain of sand abuts against the base of the Coastal Cordillera at the hill called Cerro Caracol. I searched in vain for any definite beach along the upper limit of the plain, but stream-action would long since have obscured such local deposits at this juncture. Above this level to the top of Cerro Caracol the granitic rock displayed only evidences of long continued atmospheric weathering and the vertical lines of dissection worked out by running water. Nowhere did I observe signs of the Pleistocene stand of the

sea much above the level of the plain. A small cave in the granite of the hillside in the public park by its angle of slope into the rock is shown to be artificial and having nothing in common with sea-caves.

A visit to Penco on the north of Concepcion gave little or no evidence regarding a change of level. The plain of dark sands is here wanting, that deposit being largely an ancient delta of the Rio Bio Bio. At the north end of Penco Beach, on a point of rock cut off by the railway cut from the bluff of Tertiary sandstones which here form the shore, at about twenty feet above sea-level I found shells thickly strewn in the soil together with fragments of mammalian bone, a typical mode of occurrence of Indian shell-heaps.

*Talcahuano and Tumbres Peninsula.*—I have given some account of the coast near Tumbres Peninsula in my itinerary (p. 32). There are good sea-caves on the inside of the Paps of Bio Bio at the present sea-level but none above. The surface of the Tumbres Peninsula is covered with a brownish weathered layer containing chips of quartz and schist derived from the underlying rock. Waterworn pebbles are absent except in situations about to be described as village sites. There are sloping surfaces of the bed rock at discordant levels and abundant traces of water action in cutting vales, but none of the horizontal lines marking the prolonged action of waves in cutting cliffs or heaping up beach materials.

On the southeast side of Tumbres at about 330 feet I found round patches of marine shells in the sod of the toska or surface deposit. The shells in the first example seen occupied a space about twenty-one feet in diameter in which the grass, in December, of a light color because it was dead, showed clearly the shell covered area because all about the shell tract a species of sorrel with a reddish stem and fruit grew in abundance. This plant avoids the shell deposits probably because of the lime. Observing this character of the vegetation, I went to other tracts which from a distance showed the absence of the sorrel and found them in each case the site of a thin shell deposit. One of these shell deposits was upwards of forty feet in diameter. In one of these areas I picked up a stone pestle, a cylindrical beach pebble battered by wear at both ends. With the shells were a few broken beach pebbles which seemingly could have had no use, but such pebbles were altogether absent in the weathered soil and toska rock outside of the shell deposits. It is evident that these deposits are of human origin. Darwin mentions shell deposits on Sentinella Hill at about 400 feet elevation reported to him by Dr. Jenks, the Assistant surgeon of the Beagle. At no point on the peninsula was I

able to detect anything like Pleistocene beaches or the work of waves at elevations above that of the plain of Concepcion and this plain is practically the only evidence of a former stand of the land lower than the present sea-level since the time of the Tertiary and older deposits which contain marine fossils.

Darwin was familiar with the fact that the natives carry large quantities of shell-fish inland, but in commenting on the fragments of shell-bearing forms such as sea-urchins found several miles inland from the coast he doubted the human origin of many deposits on the ground that it was improbable that the natives would transport such materials to any distance from the coast. On the contrary, it is well known that sea-urchins are an article of food in Chile. I saw in the market at Tamuca baskets of a large sea-urchin with the spines attached. The natives use for food many shell-fish which the unnaturalized European does not think of utilizing and if one objects that in the Pre-Columbian days such stores of food would decay in the course of a distant inland journey due allowance must be made for savage tastes. The "hung" meats and festering cheeses of civilized countries show how much latitude must be allowed for aberrant tastes. In the semi-arid and arid climatic zones of the Coastal Cordillera many Mollusca would become dessicated rather than putrid because of a belated consumption. In fact the unusual distance to which shell accumulations are found back from the coast of Chile appears to me quite compatible with the physical environment of an aboriginal people whose hinterland in the Longitudinal Valley was in primitive times less fruitful than the adjoining sea. Kitchen-middens occur here in every degree of accumulation from the now sparsely scattered shells in the sod marking a temporary abode to the thick shell-heap on the site of permanent habitations. Shells on the surface or buried in the superficial subaerial deposits along this coast are no more a criterion of submergence beneath the sea than elsewhere and cannot be relied upon as proving anything other than the agency of man.

*The Red Soil.*— Along the western slopes of the Coastal Cordillera there are large tracts with a red soil, the characteristic effect of the subaerial decomposition of rocks. The situation of these residual deposits, the nature of the topography without beaches or marks of wave action, and the abundant traces of the secular leaching by rains and moisture, together with the gulying of the ancient surface on which these deposits occur, alike bespeak ordinary atmospheric processes as conditioning the formation of this red earth. The occurrence of shells and other exuviae in this deposit is but an indica-

tion of man's occupation of the area for a few centuries perhaps in the past.

Pissis (1875, p. 78-81) has described the distribution of the most recent marine elevated deposits of Chile. Beginning on the north in the plain which extends from the Bay of Antofogasta to that of

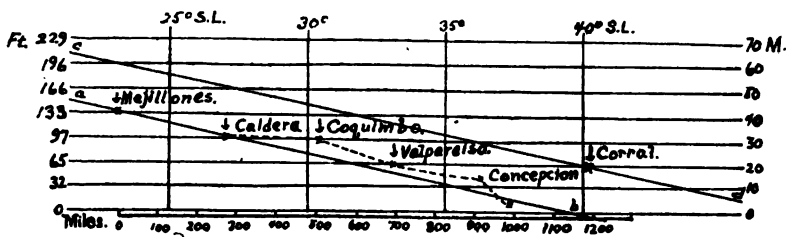


FIG. 35.— Rise to the north of the Recent uplifted marine deposits of Chile, according to the data of Pissis (1875, p. 78-81). The dotted line shows apparent warped surface from Caldera southward. The line a-b gives the mean tilt-rate from Mejillones southward. The line c-d is drawn at the same tilt-rate to touch the elevated rock bench at Corral.

Mejillones this plain, having there an altitude of forty meters, is represented by correlated deposits at constantly lower levels on the south as far as the 38th parallel. In the vicinity of Caldera the deposits rise from twenty-five to thirty meters above sea-level. About Valparaiso and San Antonio the level is maintained between fifteen and twenty meters. The city of Concepcion is built on the sands at the mouth of the Rio Bio Bio and finally at Levau the deposits rise scarcely two to three meters above the sands of the beach. Taking these data as given by Pissis and plotting the upper limit between Mejillones and Levau, the tilt-rate is shown by the graphical construction in Fig. 35. According to these observations made by Pissis as early as 1875 the coast from a point north of Valdivia shows a rise at the rate of about 0.13 ft. per mile for about 1,100 English statute miles.

Valdivia and Corral lying to the south of this group of raised deposits as noted above shows evidence of depression preceding the last slight rise of the coast. Accepting Pissis's altitudes for the height of the uplifted plain and assuming the above rate of tilting, the abandoned sea-caves south of Corral fall on a tilted plane about three meters above that of the formation of sands and shells, and may tentatively be regarded as at the sea-level under which the sands were laid down.

The fifty-five to sixty foot bench at Corral is at that place about fifty feet above the line of the abandoned sea-caves. What the attitude of this terrace is south of Corral I am unable to state. That the depression of the coast continues increasingly southwards is possibly indicated by the extensive fiord zone however much these channels may have been over-deepened by the Pleistocene glaciers. But Darwin's (1891, p. 233) account of sea-caves not now visited by the waves on the island of Chiloe, though these small caves may be more recent than those of Corral, shows the necessity of a resurvey of this coast before assuming any uniform rate of tilting over great distances.

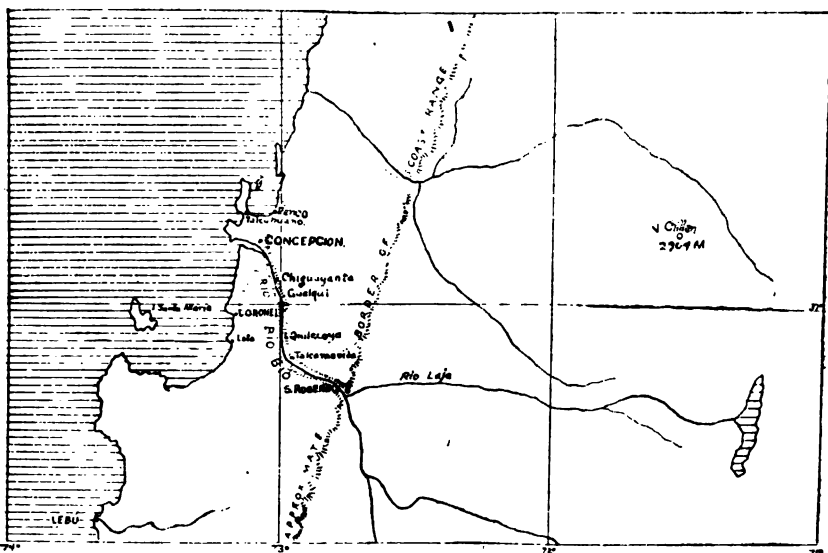


FIG 36.— Sketch map of country about Concepcion, Chile.

*Terraces of the Rio Bio Bio within the Coastal Cordillera.*— From the delta plain of the Rio Bio Bio at Concepcion there is a series of river terraces within the cañon of the river rising in altitude to San Rosendo at the border of the Longitudinal Valley. The railway from Talcahuano to San Rosendo follows the river, rising at a very uniform grade now on a lower terrace and again passing through cuts in the margins of a higher terrace. The following notes were taken on a railway journey from Concepcion to San Rosendo. The elevations of the

railway stations and distances from the terminus at Talcahuano are from the official map of the railways of Chile. The estimates of the elevations of the terraces are approximate only except at San Rosendo where measurements were made with an aneroid barometer.

Talcahuano, 0 kms. Altitude 3 M. (9.8 ft.). This is the elevation of the border of the delta of the Rio Bio Bio.

Los Pexales, 7 kms. alt. 6 M. (19.6 ft.). This is a point on the plain midway between Talcahuano and Concepcion.

Concepcion, 15 kms., alt. 9 M. (29.5 ft.). This is the elevation of the railway station near the river. The plain rises north of this point to an elevation of about forty-five feet.

Chiguayante, 25 kms., alt. 18 M. (59 ft.). This Station is within the gorge where the river flows northwest. Above this point a stony terrace appears.

Gualqui Station, 38 kms., alt. 21 M. (68.8 ft.). Terraces of alluvium judged to rise from thirty to thirty-five feet above railway, or 100 feet above sea-level. At about 120 feet above sea-level there is a sloping dissected terrace in the decomposed bed rock of the gullied sides of the cañon. The fine sand deposit continues as a terrace bordering the river, apparently a continuation of the deposit forming the Concepcion Plain. Above this terrace the side walls are deeply gullied.

Quilacoya Station, 48 kms., alt. 25 M. (82 ft.). The terrace here rises to about 105 feet above sea-level, at its edge. The railroad runs on a deposit of the dark sands. Old rock remnants of a sloping terrace are to be seen on the ravined walls of the gorge, apparently indicating an old baselevel of the river before noted as visible above Gualqui Station.

Talcamavida Station, 62 kms., alt. 34 M. (111.5 ft.). The fine dark sands form a terrace rising twenty to twenty-five feet above the Station or about 130 to 135 feet above sea-level. The general trend of the gorge from this point to San Rosendo is southeast. Above this Station in the terrace large angular stones, cobbles, and gravel appear, indicative of flood conditions with ice-rafts,—typical glacial river deposits.

Gomero Station, 69 kms., alt. 38 M. (124.6 ft.). The edge of the terrace is here about twenty feet above the railway, or about 145 feet above sea-level. Heavy gravel beds are exposed along the river above this point, with waterworn cobbles.

Bunaraqui Station, 76 kms., alt. 41 M. (134.5 ft.). Top of terrace about twenty feet higher, or about 155 feet above sea-level.

Malvoa Station, 79 kms., alt. 43 M. (141.0 ft.). Good terrace on opposite or southwest side of river. At railway station there are clays.

San Rosendo Station, 85 kms. alt. 46 M. (154.8 ft.). East of the Station there was in 1908 an excellent exposure of gravels and sands in a deep cut, rising about sixty-five feet above the railway, or to an elevation of 220 feet above sea-level. The annexed section is from a drawing made on the spot. (Fig. 37).

This section reveals a succession of river deposits varying from sands like those now transported in this portion of its course by the Rio Bio Bio to coarse gravels, including large boulders such as demand ice-rafts or the proximity upstream of glacial conditions.

The lowest bed exposed (see Fig. 37) consists of dark sand with pebbles of a volcanic rock. Above this comes a coarse gravel including a boulder of gneiss about seven feet long. Next in the section is sand with thin bands of volcanic pebbles. Above these layers comes about twenty-five feet of dark sands with a thin band of volcanic pebbles. Surmounting this and forming the surface is a layer, about twenty-feet thick, of coarsely bedded gravels and boulders, the cross-bedding of which suggests the structure of a delta front.

There are in this section thus the records of two episodes when the river transported to this point coarse gravels and boulders which it is to be presumed indicate contemporary advances of the local glaciers or times of unusual melting and discharge of coarse débris.

I saw no marine shells in any part of this terrace or on its surface, and no evidence of the presence of the sea in the deposition of the materials. The structure is quite like that of many glacial river deposits in the inland portions of glaciated North America. The lower bed of coarse gravel with boulders must have been deposited at or above sea-level as is also the case with the uppermost bed of like materials. The aggradation of the valley under glacial stream-action affords a simple explanation of these deposits without recourse to the hypothesis of a change of level in relation to the sea.

This section is the most reliable in its bearing on the altitude of the terraces, since those lower down the river were estimated only from

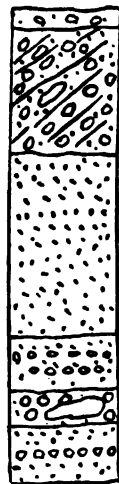


FIG. 37. — Section of Pleistocene terrace at San Rosendo, Chile, in 1908.

the elevation of their edges as seen from the train and the tops of such terraces may rise higher than the figures above given. From Concepcion at the seaward mouth of the gorge to San Rosendo along the river is a distance of 70 kms. (42.7 miles). Taking sea-level in Pleistocene time at Concepcion as forty-five feet, the San Rosendo terrace gives a uniform rise up the river of 4.3 feet per mile for the grade of the river, not in the least too steep to be within the range of streamaction for the entire distance above Concepcion. It does not appear to me therefore that the terraces of the Rio Bio Bio within the Coastal Cordillera demand a lower stand of the land than is indicated by the delta plain at Concepcion.

The traces of a higher floor of the valley shown in the faint rock-terraces within the gorge of the Bio Bio are of very ancient date. They appear to be more deeply dissected than the rock-bench at Corral with which it would be hazardous to correlate them. The tops of the low hills of Tertiary rocks piercing the plain at Concepcion are possibly nearer the level of the Corral bench, but these and other questions concerning ancient changes of level of baselevelled rock surfaces on this part of the coast of Chile await further study. I am only able to state that as the result of my own observations it appears that an elevation since late Pleistocene times has taken place at Concepcion amounting to something like forty-five feet; that at Corral and Valdivia an older Pleistocene or late Pliocene uplift of about sixty feet is indicated, and that a recent uplift of a few feet not more than ten and perhaps not more than five feet is indicated, and that, in conclusion, the coast of Chile affords a largely open field for the determination of the changes of level which it has undergone in relation to the sea during Pleistocene and late Pliocene times, involving a thorough revision of Darwin's studies on this subject in the light of criteria which were not in his time applied to the study of shore-lines.

## IX. STONE IMPLEMENTS AND POTTERY FROM LAGUNA.

By R. B. DIXON.

A number of specimens from an aboriginal camp-site near Laguna, Province of Santa Catharina, have been placed in my hands for description, by Prof. J. B. Woodworth. The specimens comprise stone implements and pottery sherds. The stone objects are of three varieties, (1) hammer-stones, (2) smoothing-stones, (3) and celts.

The hammer-stones are of a simple, world-wide type, slightly pitted on two sides where held between the thumb and fingers. The smoothing-stones are from two to three inches in length, and show on one or more sides evidences of rubbing and polishing. They were in all probability used in the manufacture of pottery, for smoothing the irregularities of the surface, both inside and out. The celt is of basalt, having a length of a little over six inches, with a width at the cutting edge of two and a quarter inches, and tapering somewhat toward the butt. One side of the implement shows somewhat greater convexity than the other and the entire surface was finished by grinding.

The pottery sherds collected represent four somewhat different types. The first of these is a smooth, reddish ware, undecorated, and with a thickness of three eighths of an inch. It was apparently used for bowl-shaped vessels of rather small size. A second type is a very coarse, red ware, from one half to five eighths of an inch in thickness. The broken quartz and gravel used for tempering is extremely coarse. The surface of the vessels was covered with thumb-prints, often of large size, where the coils had been pressed together in the process of manufacture. The vessels were probably of large size. A third type of sherd shows a heavy and rather coarse gray ware, the surface covered by a buff or yellowish slip. This ware is nearly an inch in thickness, and the smoothed surface is decorated by painted designs in red. The figures are rectilinear, and seem to be zigzags and grecques. These vessels also must have been of large size. A single sherd also with painted decoration but of much thinner ware, and evidently a fragment of a small bowl, with decoration consisting of cross-hatching around the margin only, may be regarded as related to the thick, heavy ware in type. One other type is represented by a sherd of dark gray ware, very hard burned. In thickness it is similar to the smooth red ware, but the surface is decorated by parallel rows of thumb-nail impressions.

The character of the sherds would seem to indicate that the site was one belonging to Indians of the Guarani group of the Tupi. These Indians are known to have occupied the region in this immediate vicinity at the period of the earliest European contact, and sherds resembling the second and third types here described, have been found widely throughout this coastal region as well as over large areas of Uruguay and along the lower Paraná.

## X. BIBLIOGRAPHY.

**Alcock, Frederick.**

Trade and travel in South America. 2nd. ed., London, 1907.

**Bodenbender, G.**

Sobre la edad de algunas formaciones Carboníferas de la Republica Argentina. *Revista del Mus. de la Plata*, 1895, 7, pt. 1, p. 131-148.

**Branner, J. C.**

Decomposition of rocks in Brazil. *Bull. Geol. soc. of America*, 1896, 7, p. 255-314.

Geologia elemental, preparada con referencia especial aos Estudantes Brasileiros. Laemmert & C. Editores, Rio de Janeiro e São Paulo, 1908.

Bibliography of the geology, mineralogy, and palaeontology of Brasil. *Bull. Geol. soc. Amer.*, 1909, 20, p. 1-132.

**Brobritzhoffer.**

History of the Abipones. 2, p. 6. (Cited by Darwin).

**Bross, H.**

Glasiale spuren in Paraná, Brasilien. *Centralblatt für mineral. geol. und palaeont.*, 1909, p. 558-561.

**Campos, Cicero de.**

Report of a geological survey of a part of the state of Paraná. Brazilian engineering and mining review, 1908, 5, p. 3.

**Darwin, Charles.**

Observations of proofs of recent elevation of the coast of Chile, made during the survey of His Majesty's ship Beagle, etc. *Proc. Geol. soc. London*, 1837, 2, p. 446-449.

Journal of researches in the natural history and geology of the countries visited during the voyage of H. M. S. Beagle round the World. 2nd ed., London, 1845.

Geological observations. London, 1846.

**Darwin, Francis.**

More letters of Darwin. 2 vols., New York, 1908.

**Derby, O. A.**

Mittheilung eines briefes von Herrn O. A. Derby über spuren einer Carbonen eiszeit in Südamerika. *Neues jahrbuch mineralogie*, 1888, 2, p. 172-176.

Decomposition of rocks in Brazil. *Journ. geology*, 1896, 4, p. 529-540.

The serra do Espinhaço, Brazil. *Journ. geology*, 1906, 14, p. 388.

The sedimentary belt of the coast of Brazil. *Journ. geology*, 1907, 15, p. 63-75.

Estudios geologicos en el Brazil. *Trabajos del Cuarto congreso científico (1° Pan-Americano)*, 1911, 11, p. 498-507.

**Dutton, C. P.**

Earthquakes. New York, 1904.

**Eckhardt, Wilh. R.**

Palaeoklimatologie. Leipzig, 1907.

**Ferreira, Francisco Ignacio.**

Diccionario Geographico das Minas do Brasil. Rio de Janeiro, 1885.

**Fricker, Karl.**

The Antarctic regions. London, 1900.

**Geikie, Sir Arch.**

Text-book of geology. 4th ed. 2 vols., London, 1903.

**Gorringe, H. H.,** Lieutenant-Commander, U. S. N.

The coast of Brasil. Vol. 1. From Cape Orange to Rio Janeiro. U. S. hydrographic office. Bureau of navigation. No. 43. Washington, 1873.

**Halle, Thore G.**

On the geological structure and history of the Falkland Islands. Bull. Geol. instit. Univ. Upsala, 1911, 11, p. 115-229. Colored geological map and 10 pls.

**Hartt, Chas. Fred.**

Geology and physical geography of Brasil. Boston, 1870.

**Hooker, Joseph D.**

Himalayan journals. 2 vols., London, 1854.

**Humboldt, Alex.**

Personal narrative of travels to the equinoctial regions of America. Bohn edition, 2 vols., London, 1852.

**Hunter and Rosenbusch.**

In Tschermak's Mineral. und petrog., 1890, 11.

**Kaemtz, L. F.**

A complete course of meteorology. Translated by C. V. Walker. London, 1845.

**Lesley, J. Peter.**

Dictionary of fossils of Pennsylvania. 4 vols., 1889.

**Leyell, Charles.**

Principles of geology. 11th ed., 2 vols., New York, 1887.

**Malte-Brun.**

Geographie universelle, mise au courant par Th. Lavalee. 6 vols., Paris, 1857.

**Oddone da Roma, Emilio.**

Quelques constantes sismiques trouvées par les macrosismes. Assoc. sismol. internat. bureau central. Strassburg, 1907.

**Oldham, R. D.**

Report on the great earthquake of 12th June, 1897. Mem. Geol. surv. of India, 1899, 29, p. 1-xxx, 1-379, with 44 plates and 3 maps.

**Pissis, A.**

Geografia física de la Republica de Chile. Paris, 1875. Atlas de 23 laminas.

**Pumpelly, R.**

The relation of secular rock disintegration to loess, glacial drift, and rock-basins. Amer. journ. sci., 3rd ser., 1879, 17, p. 133-144.

**Rozas, Alfonso Rodriguez, y Cruzat, Carlos Gajardo.**

La catastrophe del 16 de Agosto de 1906 en la Republica de Chile. Santiago de Chile, 1906.

**Rosa, Jose Vieira de.**

Chorographia de Santa Catharina. Florianopolis, 1905.

**Russell, Thomas.**

Meteorology. New York, 1895.

**Sayles, Robert W., and La Forge, L. A.**

The glacial origin of the Roxbury conglomerates. Science, 1910, new ser., 32, p. 723-724.

**Siemiradski, J. v.**

Geologische reisebeobachtungen in Südbrazilien. Sitzungsber. k. Akad. wiss. Wien., 1898, 107, abth. 1, p. 23-39, pl. 1.

**Simroth, Heinrich.**

Die pendulationstheorie. Leipzig, 1907.

**Smith, H. H.**

Brazil and the Amazons, and the coast. New York, 1879.

**Steffen, H.**

Contribuciones para un estudio científico del terremoto del 16 de Agosto de 1906. Publicado en los anales de la Universidad en Mayo y Junio de 1907, Santiago de Chile, 1907.

**Sundt, Lorenzo.**

Breve reseña de la geología Chilena. In Eduardo Poirier: Chile en 1908. Appendice, p. 37-44. Santiago de Chile, 1909.

**Ulloa, Don Juan and Don Antonio de.**

A voyage to South America. 3rd ed., 2 vols. London, 1772.

**Wallace, Alfred R.**

A narrative of travels on the Amazon and Rio Negro. 4th ed., London, 1892.

**White, I. C.**

Relatorio final apresentado a S. Ex. o Sr. Dr. Lauro Severiano Müller. Comissão de estudos das minas de Carvão de Pedra de Brazil. Rio de Janeiro, 1908. (Printed in Portuguese and English).

**Whymper, Edward.**

Travels amongst the Great Andes of the Equator. New York, 1892.

**Wieland, G. R.**

The Williamsonias of the Mixteca Alta. Botanical gazette, 1909, 48, p. 441-442.

**Woodward, A. Smith.**

Considerações sobre alguns peixes terciarios dos schistes de Taubeté, Estado de São Paulo, Brazil. Revista do Museu Paulista. 1898, 3, p. 63-75.

**Woodworth, J. B.**

Review of *La face de la terre* by Edouard Suess. *Science*, 1898, new ser., 7, p. 803-806.

*Papers and notes pertaining to the Expedition.*

Papers and notes pertaining to the Expedition.

**Greene, Jerome, and Warren, Joseph.**

[Correspondence relating to appointment of Thomas Barbour, Archibald Cary Coolidge, and Jay Backus Woodworth, delegates to Pan-American Congress at Santiago de Chile]. *Boletin 2, IV Congreso Científico (1° Pan-Americano)*, 1908, p. 118-119.

**Ward, R. DeC.**

Government meteorological work in Brazil. Monthly weather review, 1908, 36, August, p. 254-256; Sept., p. 290-292.

Notes on weather and climate made during a summer trip to Brazil, 1908.

Monthly weather review, October, 1908, 36, p. 333-339.

The southern campos of Brazil. *Bull. Amer. geog. soc.*, 1908, 40, p. 652-662.

The national exposition at Rio de Janeiro. *Pop. sci. mo.*, 1909, 74, p. 105-123.

An outline of the economic climatology of Brazil. *Bull. Geog. soc. of Phila.*, 1909, 7, April, p. 53-66; June, p. 135-144.

**Woodworth, J. B.**

Shaler Memorial Expedition. *Economic geologist*, 1908, p. 359-361.

*La expedicion memorial de Shaler en Brasil y Chile.* (Read by title). *Boletin 3, IV Congreso Científico (1° Pan-Americano)*, 1908, p. 151.

The Shaler Memorial Expedition to Brazil and Patagonia, 1908-09. *Amer. journ. sci.*, 1908, ser. 4, 26, p. 404.

Report of the delegates of the United States to the Pan-American scientific congress held at Santiago, Chile, December 25, 1908, to January 5, 1909. Washington, 1909. Appendix I. Report on Section 3, subsection 4, Geology and related subjects, p. 34-35.

Permo-Carboniferous conglomerates in south Brazil. (Abstract). *Bull. Geol. soc. Amer.*, 1910, 21, p. 779.



**PLATE 1.**

PLATE 1.

VALLE DO RETIRO NEAR PETROPOLIS.

View in the Serra do Mar near head of the Valle do Retiro back of Petropolis looking down the Valle do Retiro across the Valley of the Piabanha, a stream flowing north to join the Parahyba. Pedra d'Aço, the culminating peak of the radiating ranges, of which the mountains in the background form a part, attains an elevation of 2,230 metres (7,306 ft.) A region of deep dissection of schistose rocks intruded by bosses of granite and dikes of more basic rocks, the schists and granites probably of Pre-Devonian age as farther south in the Serra do Mar region. Page 7.



PHOTO BY J. B. WOODWORTH.

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VAL DO RITIRO, NEAR PETROPOLIS.

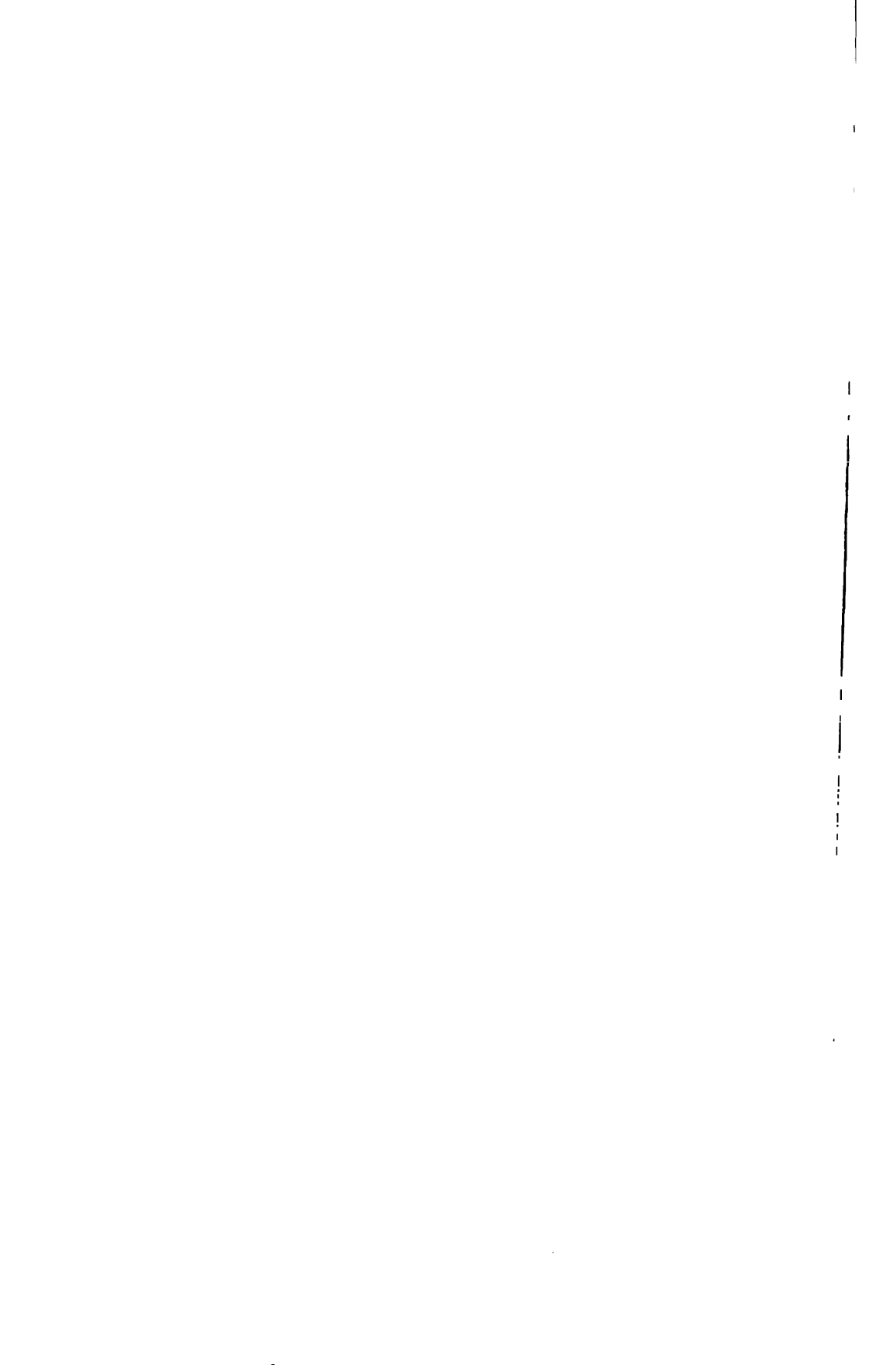


**PLATE 2.**

PLATE 2.

GRANITE BOULDERS DUE TO WEATHERING.

View on the shore of Florianopolis Island, Santa Catharina; on shore of bay south of the city of Florianopolis. This type of surficial boulder, due to secular weathering of the granite, is common in the granitic regions along the slopes and at the base of the Serra do Mar, particularly at sea-level. The well-known boulders of the "Furnas das Agassiz" at Tijuca, which with other phenomena gave rise, at the time of the Thayer Expedition to Brazil, to the now abandoned hypothesis of the glacial origin of these detached blocks, belong in the same class of effects of secular weathering since Tertiary times. Page 113.



PHOTO BY J. B. WOODWORTH.

WEATHERED BOULDERS, FLORIANOPOLIS.

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**PLATE 3.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 3.

The campos of São Paulo, between Faxina and São Pedro de Itararé a few miles west of the former place on the Carboniferous sandstone terrane, showing the dissected peneplain of southwestern São Paulo, and mode of travelling by "trolley." Page 13.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

THE CAMPOS OF SÃO PAULO, WITH PARTY EN ROUTE.



**PLATE 4.**

**PLATE 4.**

**Ruins of the old Spanish fort at Penco (ancient Concepcion) on the eastern shore of Concepcion Bay, destroyed in the earthquake and tsunami of May 24, 1751. View looking N. 56° E, mag., December 13, 1908. These walls are the sole standing remnant of the old town of Concepcion. Page 33.**



PHOTO BY J. B. WOODWORTH.

RUINS OF OLD FORT AT PENCO, CHILE.

HELOTYPE CO., BOSTON.



**PLATE 5.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 5.

Pleistocene glacial gravels at San Rosendo, Chile, on the north bank of the Rio Bio Bio just inside the Longitudinal Valley. December 24, 1908, looking N. mag., from the railroad tracks just east of the Station. Page 131.



PHOTO BY J. B. WOODWORTH.

PLEISTOCENE GLACIAL GRAVELS AT SAN ROZENDO, CHILE.

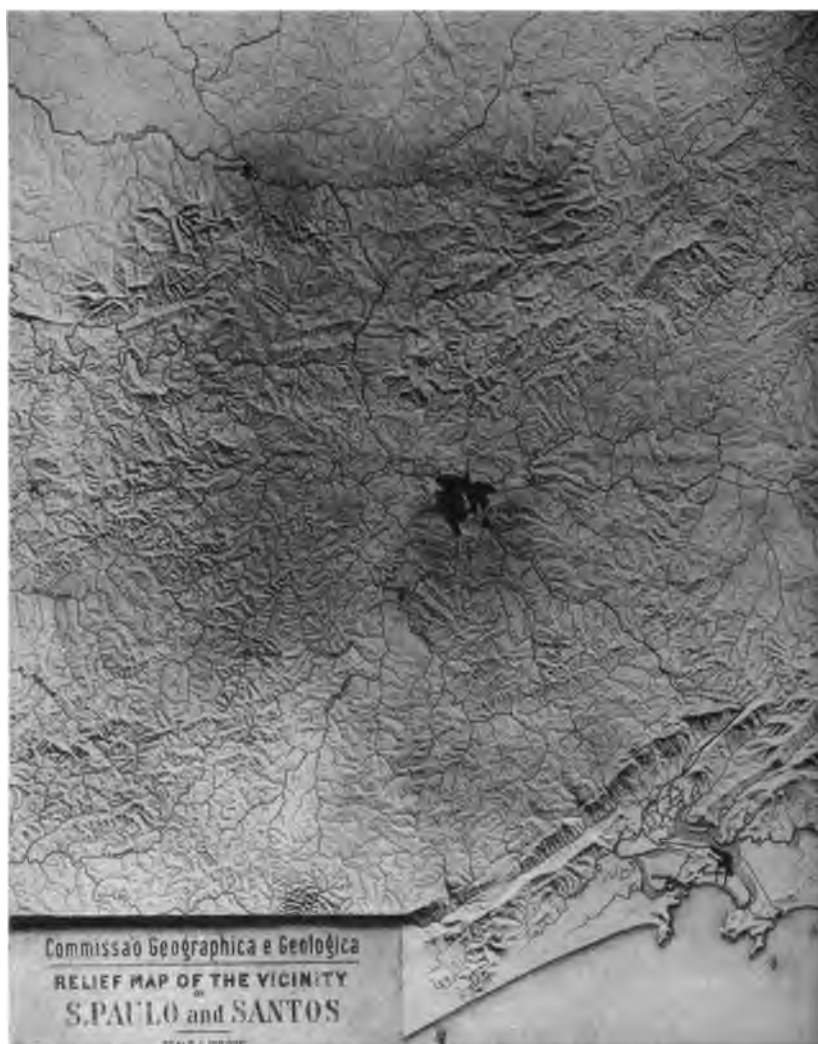
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**PLATE 6.**

PLATE 6.

Reproduction of a model of a portion of the state of São Paulo made by the Geographical and Geological Commission of São Paulo and based on the topographic surveys of Horatio E. Williams. The model brings out the detail of the erosion of the metamorphic and igneous Pre-Devonian belt forming the Atlantic slope of the highlands near Santos; the Serra do Japy southwest of Jundiáhy. The roughened surface northeast of São Paulo may be regarded as the dying out of the Serra da Mantiqueira which range rises rapidly to the northeast of the area shown in the relief map. Except for the Tertiary basin in the smoothened area about São Paulo, the topography is developed on metamorphic and igneous rocks of the Pre-Devonian terrane. Page 99.



THE PLATEAU OF SOUTH BRAZIL IN EASTERN SÃO PAULO.



**PLATE 7.**

**PLATE 7.**

**The southern part of the city of Curityba, Paraná, looking west over the gently rolling surface of the peneplain developed on crystalline Pre-Devonian schists. The surface lies at an altitude of about 900 meters. Page 102.**

Exp. to Brazil & Chile.

Plate 7.



PHOTO BY J. S. WOODWORTH.

HELIOTYPE CO., BOSTON.

CURITYBA AND THE PENEPLAIN ON THE METEMORPHICS IN PARANÁ.



**PLATE 8.**

PLATE 8.

The Devonian area in Paraná looking northeastward, from the city of Ponta Grossa standing on Devonian shales, to the rising, rounded back of the westward dipping slope of the Devonian sandstone cuesta whose crest forms the sky-line of the view. Page 103.



PHOTO BY J. S. WOODWORTH.

HELIOTYPE CO., BOSTON.

THE DEVONIAN AREA AND THE CREST OF THE SANDSTONE CUESTA SEEN FROM PONTA GROSSA.

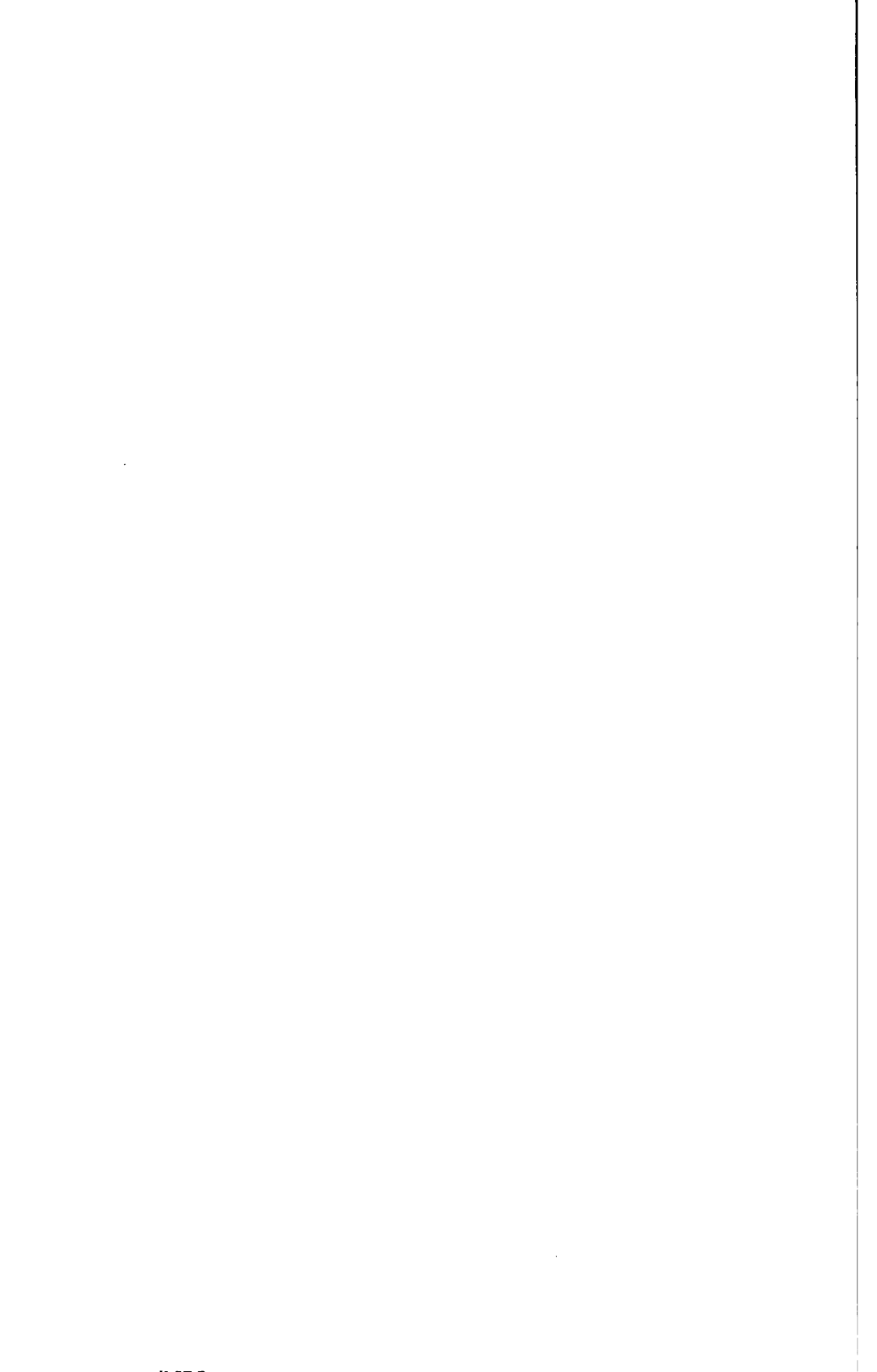


**PLATE 9.**

PLATE 9.

The campos of São Paulo looking north from a point about eighteen kilometers west of Bury (Porto Apiaby), 128 miles inland and westward from the port of Santos, showing the smoothened surface of the peneplain of the Permian area, which is usually more rolling than shown in the view. Freight wagons and ant-hills in view. Treeless condition characteristic of large tracts. Page 102.

Exp. to Brazil & Chile.

Plate 9.



PHOTO. BY J. B. WOODWORTH.

THE CAMPOS OF SÃO PAULO, ON SANDSTONE TERRANE.

HELIOTYPE CO., BOSTON.



**PLATE 10.**

PLATE 10.

The Morro do Monge (Monk's Hill), near Lapa, Paraná; looking S. 46° E. mag., from eastern limits of village, August 14, 1908, showing cliffs of heavy bedded Permian sandstone overlying beds with waterworn gravels and out-cropping layers carrying striated stones. Page 67.



PHOTO BY J. S. WOODWORTH.

THE MORRO DO MONGE NEAR LAPA, PARANÁ.



**PLATE 11.**

**WOODWORTH.—Geological Expedition to Brazil and Chile.**

**PLATE 11.**

**View from Restinga Secca on the railroad between Ponta Grossa and Curityba looking S. W. over the Permian area in the valley of the Iguassú. August 4, 1908. Page 104.**



PHOTO BY J. B. WOODWORTH.

PERMIAN AREA IN THE VALLEY OF THE IGUASSÚ SEEN FROM RESTINGA SECCA, PARANÁ.

HELIOTYPE CO., BOSTON.



**PLATE 12.**

PLATE 12.

The gorge of the Iguassú at Serrinha, Paraná, west of Curityba. The Iguassú after leaving the baselevelled region about Curityba flows for several miles across the sandstones and boulder-beds at the base of the Permian system. The basal beds are regarded by some Brazilian geologists as possibly Devonian. Page 65.

Exp. to Brazil & Chile.

Plate 12.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

CAÑON OF THE IGUASSÚ AT SERRINHA, PARANÁ.



**PLATE 13.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 13.

Pleistocene surficial gravels at Tamanduá, Paraná, in a railroad cut north of the Station, on the westward dip-slope of the Permian sandstone cuesta. These gravels occur on the interstream slopes here and there. Page 108.



PHOTO BY J. B. WOODWORTH.

PLEISTOCENE GRAVELS AT TAMANDUÁ, PARANÁ.

HELIOTYPE CO., BOSTON.



**PLATE 14.**

PLATE 14.

Section in the red residual clays of the campos bordering the valley of the Iguasú at Lago, south of Ponta Grossa, Paraná. In outward respects similar to the *terra roxa*. Ant-hills shown on the surface. Page 112.



PHOTO BY J. B. WOODWORTH.

HELIO TYPE CO., BOSTON.

RED CLAYS AT LAGO, PARANÁ, VALLEY OF THE IGUAZÚ.



**PLATE 15.**

PLATE 15.

Sketch map of the geology of south Brazil, based upon surveys by Dr. Orville A. Derby, Dr. I. C. White, the publications of Dr. J. C. Branner, and upon field observations by Dr. Euzebio P. de Oliveira and the writer. The boundary of the trap sheet and consequently of the sedimentary area about Lages in Santa Catharina is drawn without any claim to approximation of its true position on the south, and the eastern limits of the effusive trap sheets in western São Paulo and northern Paraná are likewise indefinite. No attempt is made to delineate the numerous exposures of intrusive sheets giving rise to the *terra roxa* of São Paulo and northern Paraná. Page 41.

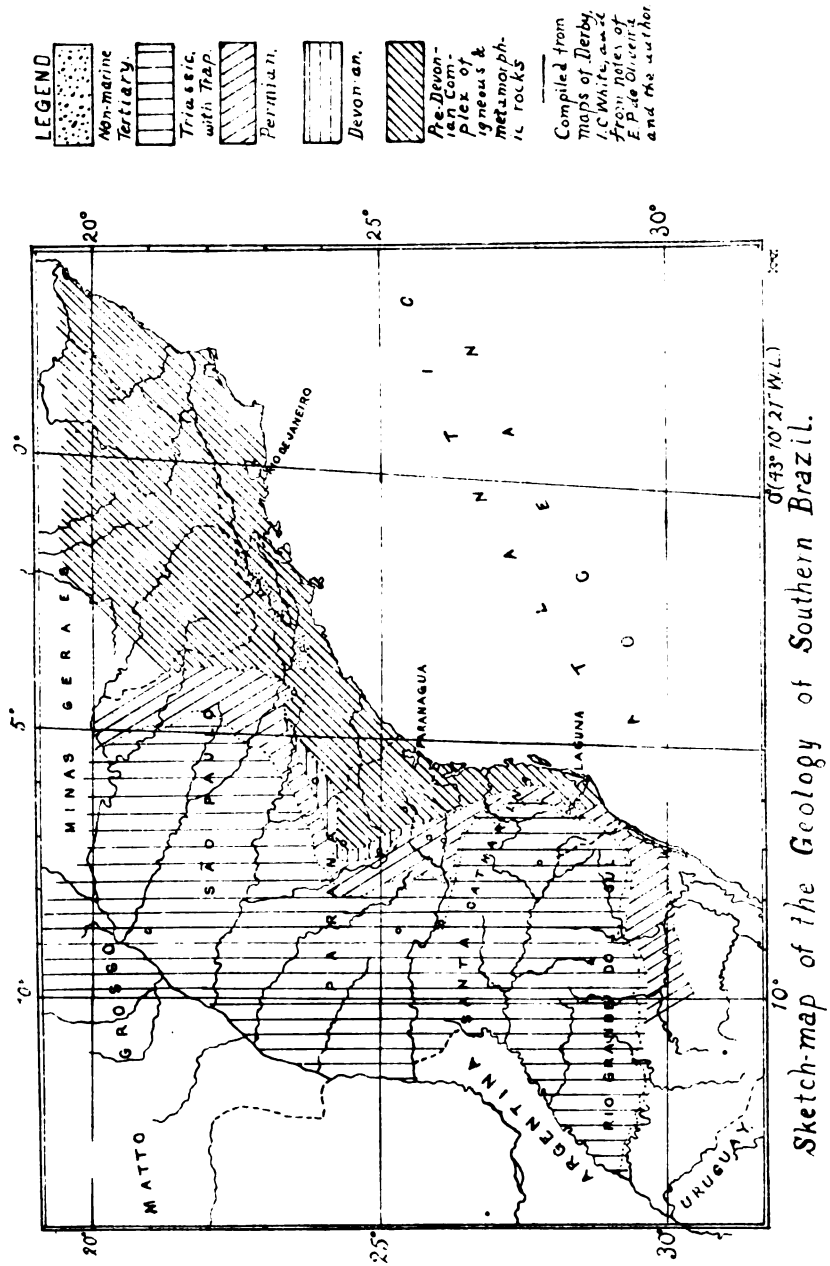




**PLATE 16.**

PLATE 16.

THE SERRA GERAL FROM MINAS IN THE TUBERÃO VALLEY.

The dim wall in the background is the escarpment of erosion formed by the Triassic trap sheets and the underlying sandstones, below which comes the Permian shales. The foreground, looking up the Tuberão just east of the Lauro Müller railway station is on the Permian plant-bearing shales. The coal mines at Minas occur at a higher level to the left of the view. According to Dr. I. C. White this wall from the top down presents the following section:—

1. Eruptive rocks, mostly diabase, amygdaloidal and otherwise, 600 M.
2. Massive grey and red sandstones and conglomerates with intruded sheets and dikes of diabase. 200 M.

Red sandstones and shales, a massive red sandstone at the base resting with slight unconformity upon limestone, approximately 100 M. The rocks below are referred to in the accompanying text. Page 92.



PHOTO BY J. B. WOODWORTH.

THE SERRA GERAL FROM MINAS IN THE TUBERÃO VALLEY.

HELIO TYPE CO. BOSTON.



**PLATE 17.**

PLATE 17.

RIO DAS MAROMBAS IN SANTA CATHARINA.

View looking east across typical tributary of the Paraná in the trap plateau on the pack-train route between Corytibanos and Porto da União. Butia palms and araucarian pines, with smoke of forest fire on left. Photo by J. B. W., August 30, 1908. The road crosses the Marombas northwest of Corytibanos. The view is looking southward. The river flows toward the right, southwestward towards its junction with the Rio Canoas, a tributary of the Rio Uruguay. The ferry is referred to on page 27.

Exp. to Brazil & Chile.

Plate 17.



PHOTO BY J. B. WOODWORTH.

THE RIO MAROMBAS IN THE TRAP PLATEAU OF SANTA CATHARINA.

HELIOTYPE CO. BOSTON.



**PLATE 18.**

PLATE 18.

Augite porphyrite dike with numerous inclusions of sandstone, shale, and fragments of vesicular lava, about six miles north of Lages on the road to Corytibanos, Santa Catharina.

The cutting edge of the palaeontological hammer points out a small block of red sandstone. The upper long hunting knife point rests on a fragment of included trap; the German army knife lower down points to a light colored sandstone. View taken in a roadside wash-out, August 28, 1908. Page 95.

Exp. to Brazil & Chile.

Plate 18.

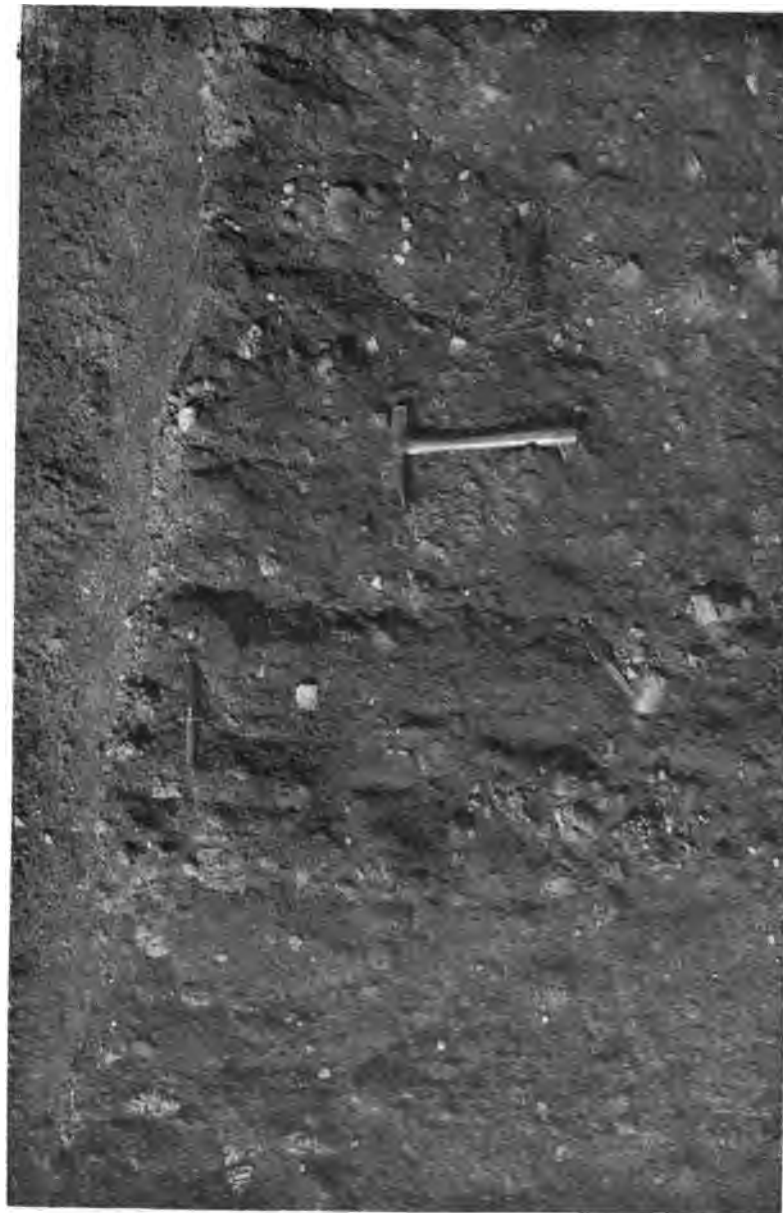


PHOTO BY J. S. WOODWORTH.

HELIOTYPE CO., BOSTON.

BASIC DIKE WITH INCLUSIONS NEAR LAGES, SANTA CATHARINA.



**PLATE 19.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 19.

Map of route from Rio Negro to Lages and return to São João and Porto da União da Victoria.

This map is based on a manuscript map in possession of the Serviço Geológico e Mineralógico do Brasil. The route was plotted from notes taken by Dr. Eusebio Paulo de Oliveira. Light tricornered points represent camps going southward, solid symbols those on the return journey. Dates are given, *e. g.* viii. 27-28, should be read "night of August 27th to morning of August 28th. See page 15.

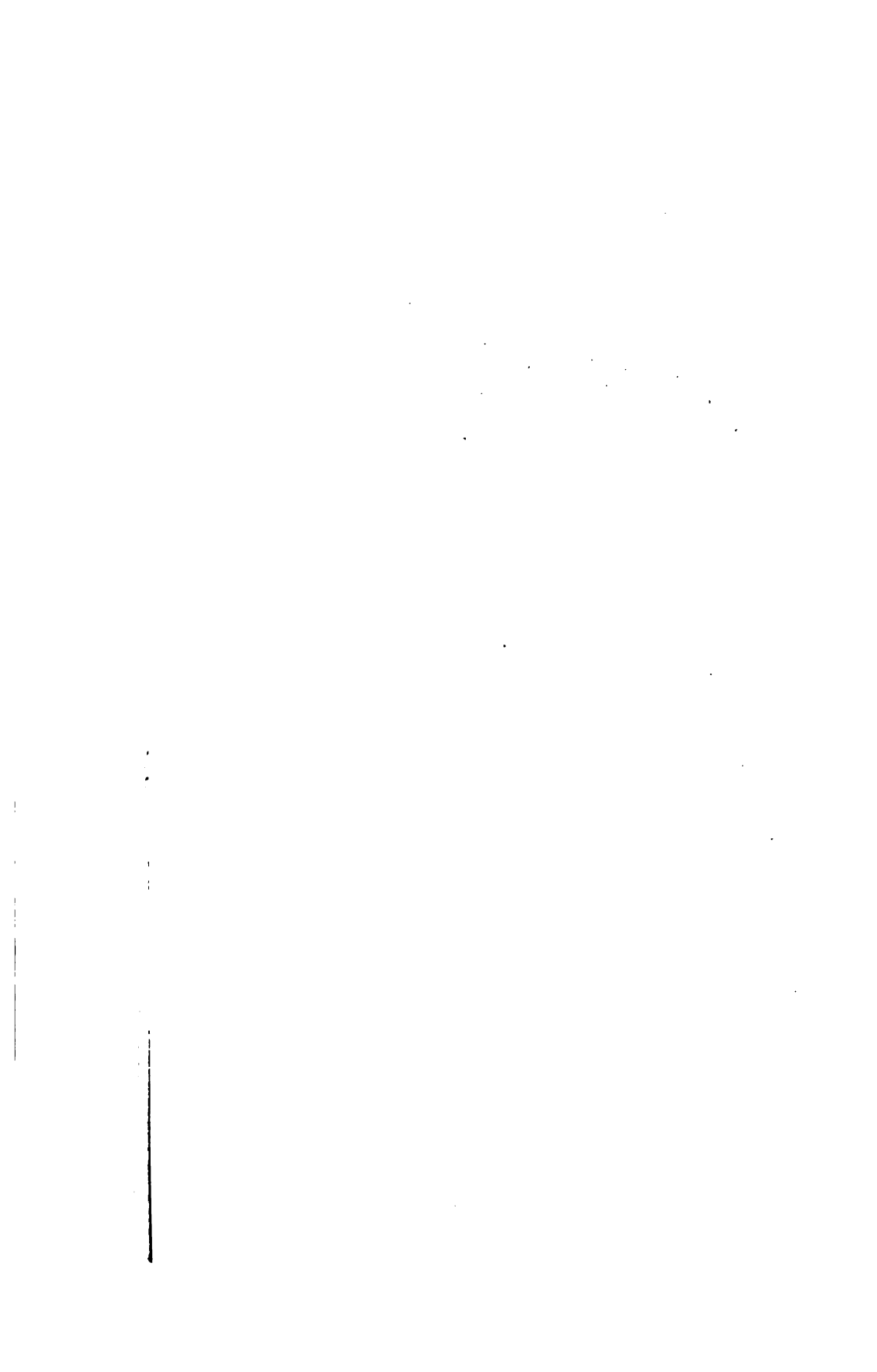




**PLATE 20.**

PLATE 20.

BOULDER OF PRE-PERMIAN CONGLOMERATE IN PERMIAN SANDSTONES NEAR  
VILLA RAFFORD STATION, SAO PAULO.

This boulder lies in the decomposed glacial sands of the railway cut between kilometer posts 199 and 200 west of the railway station. It is composed of quartzite pebbles unlike any portion of the Permo-Carboniferous or Devonian series known to me in this district. There is a specimen in the collection of the Museum at São Paulo, said by Dr. Pacheco to be identical with this rock, which has all the characters of a basal conglomerate of a marine series of Pre-Devonian age, possibly to be located in the metamorphosed sedimentary belt on the east of the area in which these fragments have been found. Page 57.

Exp. to Brazil & Chile.

Plate 20.



PHOTO BY J. B. WOODWORTH.

BOULDER OF CONGLOMERATE IN PERMIAN AT VILLA RAFFORD, SÃO PAULO.

HELIOTYPE CO. BOSTON



**PLATE 21.**

PLATE 21.

TILLITE BED AND GLACIATED STONES NEAR SENGÉNS, PARANÁ.

This view was taken on the 16th of September, 1908, in the then relatively fresh railway cuttings between Sengéns and Itararé, between kilometer posts 234 and 235 on the south side of the Rio Jaguaricatu. The wall of rock in the background is a somewhat softened boulder-clay with scattered stones and small boulders, one of which is seen protruding to the right of the white square (block of field-labels). The loose stones in the foreground were picked up in the immediate vicinity on the floor of the excavation. The largest boulder is granite; the next but smaller on the left is a white sandstone, probably of the basal Devonian; the stone on the extreme right is a dark greenish rock not determined. To the left of the hammers is to be seen a well-striated reddish brown sandstone, probably a fragment of the disrupted glacial floor.

Page 62.

Exp. to Brazil & Chile.

Plate 21.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

TILLITE BED AND GLACIATED STONES NEAR SENGÉNS, PARANÁ.



**PLATE 22.**

PLATE 22.

BLOCK OF FINE WHITE SANDSTONE NINE FEET LONG IN TILLITE BED NEAR  
SENGÉNS, PARANÁ.

View taken September 16, 1908, in railway cut between kilometer posts 235 and 236 between Sengéns and Itararé, south side of track, showing a large block 9 ft. (or three meters) long of a fine-grained white siliceous sandstone, embedded in a typical glacial conglomerate or tillite. This bed lies a few feet above strata of the same lithological appearance as the erratic. Page 62.



PHOTO BY J. B. WOODWORTH.

BLOCK NINE FT. LONG IN TILLITE AT SENGENS, PARANÁ.

HELIOTYPE CO., BOSTON.



**PLATE 23.**

PLATE 23.

SPHEROIDAL SEPARATION IN TILLITE NEAR RIO NEGRO, SANTA CATHARINA,  
SOUTH OF THE RIVER OF THE SAME NAME.

View taken September 20, 1908, of a roadside cut, looking northwest, about half an hour's ride from Rio Negro on the road to São Bento, on the south side of the Rio Negro. This bed overlies the shales shown in Plate 24. See small map page 68.

Exp. to Brazil & Chile.

Plate 23.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

SPHERICAL SEPARATION IN TILLITE NEAR RIO NEGRO, SANTA CATHARINA.



**PLATE 24.**

PLATE 24.

Ice-rafted boulder and stones in shales near Rio Negro, Santa Catharina. Same locality as Plate 23. This shale underlies the earthy bed shown in Plate 23, and contains near bottom of view a 1.5 inch band of the same material. Surface shows the herbaceous growth of the open lands between forested tracts. The boulder is a gneiss. Page 68.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

ICE-RAFTED BOULDERS AND STONES IN PERMAN SHALES NEAR RIO NEGRO, SANTA CATHARINA.



**PLATE 25.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 25.

Water-laid conglomerate at Orleans, Sta. Catharina. Page 73.



PHOTO BY J. S. WOODWORTH.

WATER-LAID CONGLOMERATE AT ORLEANS, SANTA CATHARINA.

HELIOTYPE CO., BOSTON.



**PLATE 26.**

PLATE 26.

Permian shales resting on granite, with boulder, near Minas, Sta.  
Catharina. Page 74.



PHOTO BY J. B. WOODWORTH.

HELIOTYPE CO., BOSTON.

PERMIAN SHALES RESTING ON GRANITE NEAR MINAS, SANTA CATHARINA.



**PLATE 27.**

PLATE 27.

Glaciated pebbles from tillite beds of Paraná. Page 76.



PEBBLES FROM TILLITE BEDS OF PARANÁ.

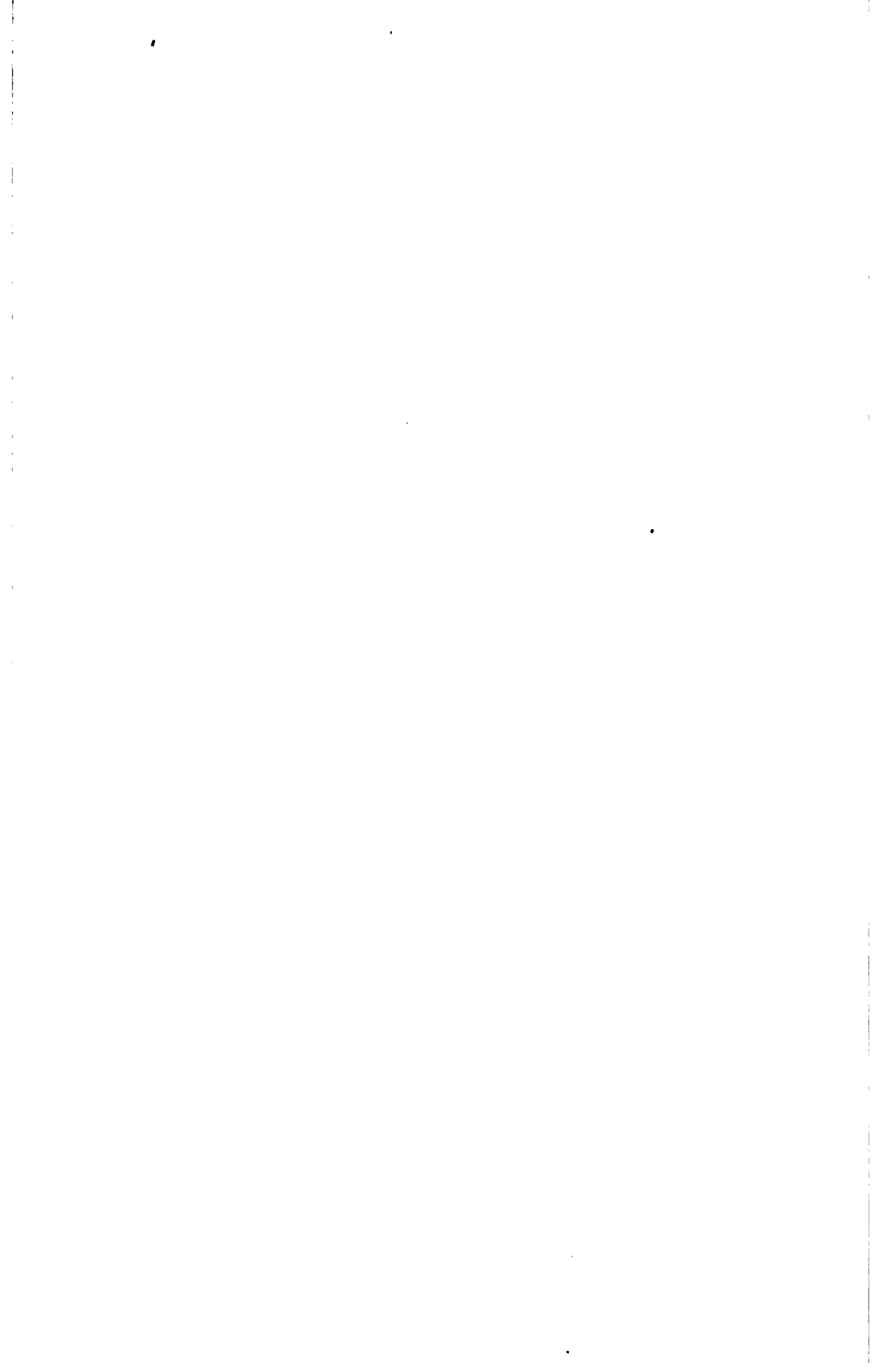
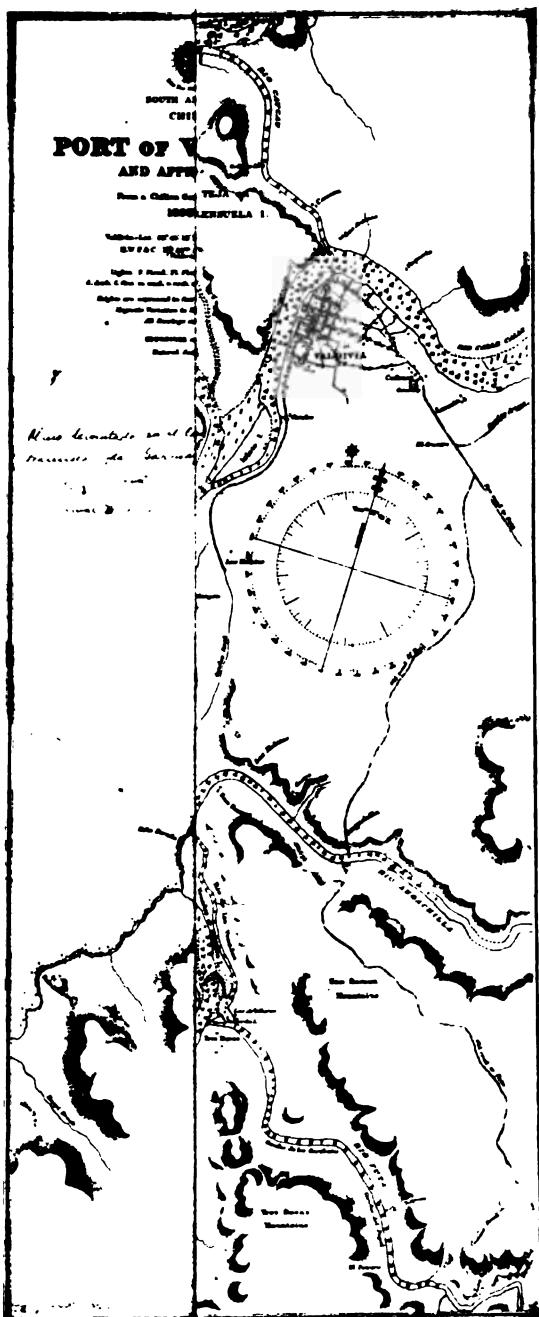


**PLATE 28.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 28.

The coast chart of Valdivia River and Corral entrance, Chile. Page 122.



WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 29.

Corral and the Cordillera Costal. Page 122.



PHOTO BY J. B. WOODSWORTH

HELIOGRAPH BY J. B. WOODSWORTH

CORRAL AND THE COASTAL CORDILLERA, CHILE.



**PLATE 30.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 30.

Rock-terrace around Mansera Island, Corral Harbor, Chile. Page 122.



PHOTO BY J. B. WOODWORTH.

ROCK TERRACE AROUND MANZERA ISLAND, CORRAL HARBOR.

HELIOTYPE CO., BOSTON.



**PLATE 31.**

Woodworth.—Geological Expedition to Brazil and Chile.

PLATE 31.

Rock-terrace on Valdivia River opposite Cutupal. Page 122.



PHOTO. BY J. B. WOODWORTH.

ROCK TERRACE IN VALDIVIA RIVER OPPOSITE CUTUPAI.

MELOTYPE CO., BOSTON.



**PLATE 32.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 32.

Drong of schist on fifty to sixty foot terrace near English Bay, south of Corral entrance, Chile. Page 123.



PHOTO BY J. B. WOODWORTH.

DRONG OF SCHIST ON 50-60 FT. TERRACE NEAR ENGLISH BAY.

HELIOTYPE CO., BOSTON.



**PLATE 33.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 33.

Sea-cave at upper marine limit near Palo Muerto Point, south of Corral entrance, Chile. Page 124.

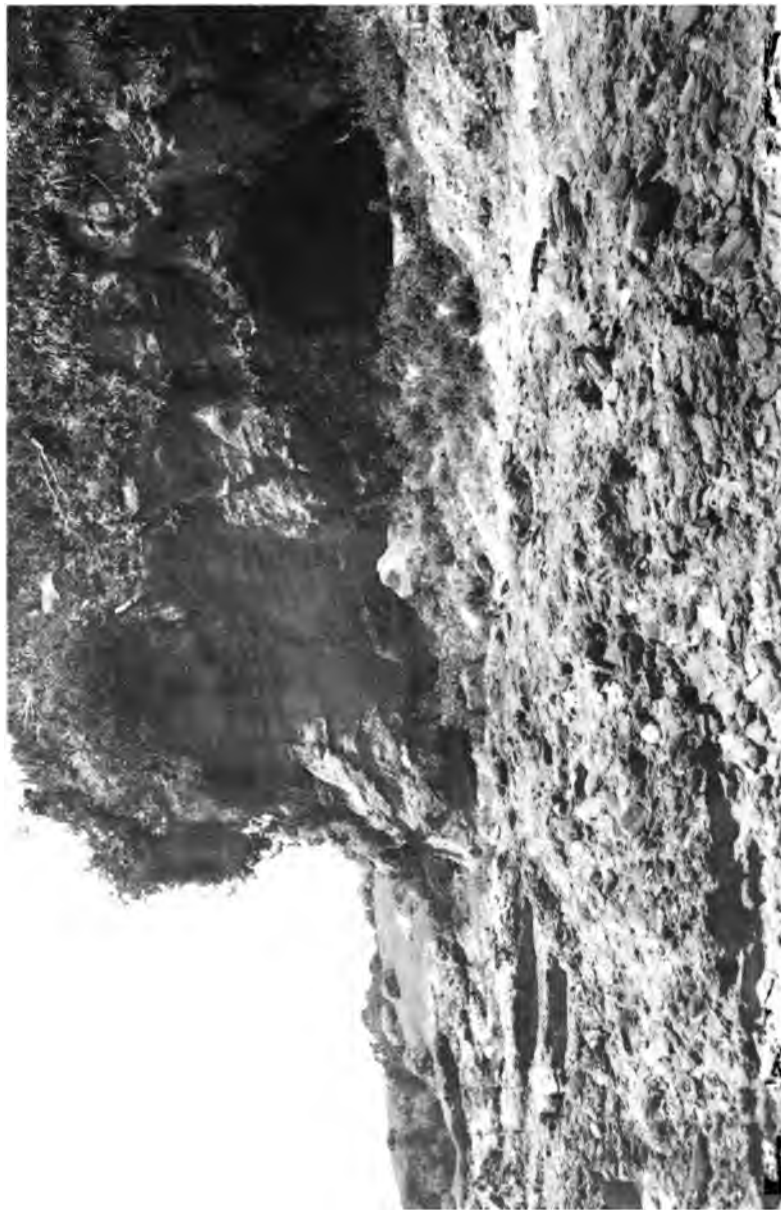


PHOTO BY J. B. WOODWORTH.

SEA-CAVE AT UPPER MARINE LIMIT NEAR PALO MUERTO POINT.

HELOTYPE CO., BOSTON.



**PLATE 34.**

**Woodworth.—Geological Expedition to Brazil and Chile.**

**PLATE 34.**

**Coast chart of Concepcion Bay, Chile. Page 125.**

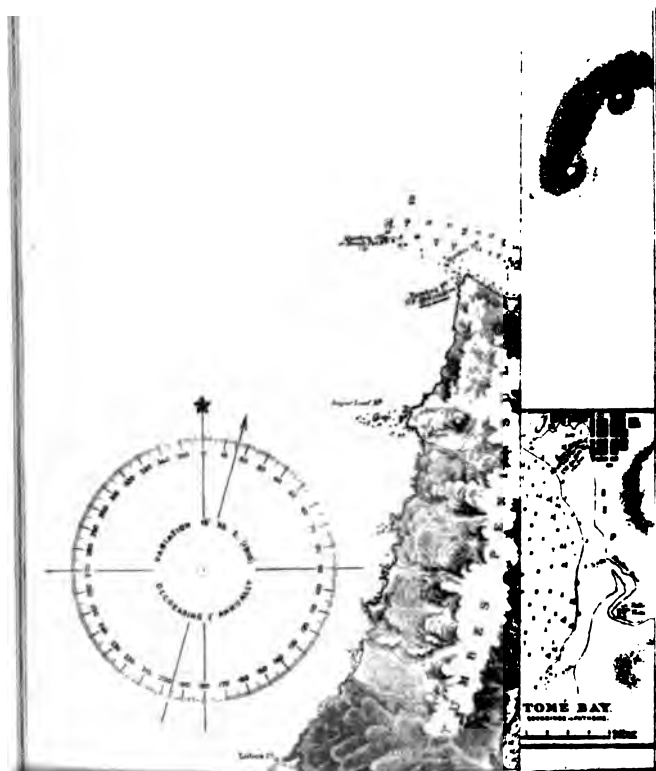




**PLATE 35.**

WOODWORTH.—Geological Expedition to Brazil and Chile.

PLATE 35.

Talcahuano and the country south of Concepcion Bay. Page 126.



PHOTO BY J. B. WOODWORTH.

TALCAHUANO AND THE COUNTRY SOUTH OF CONCEPCION BAY.

HELIOTYPE CO., BOSTON.

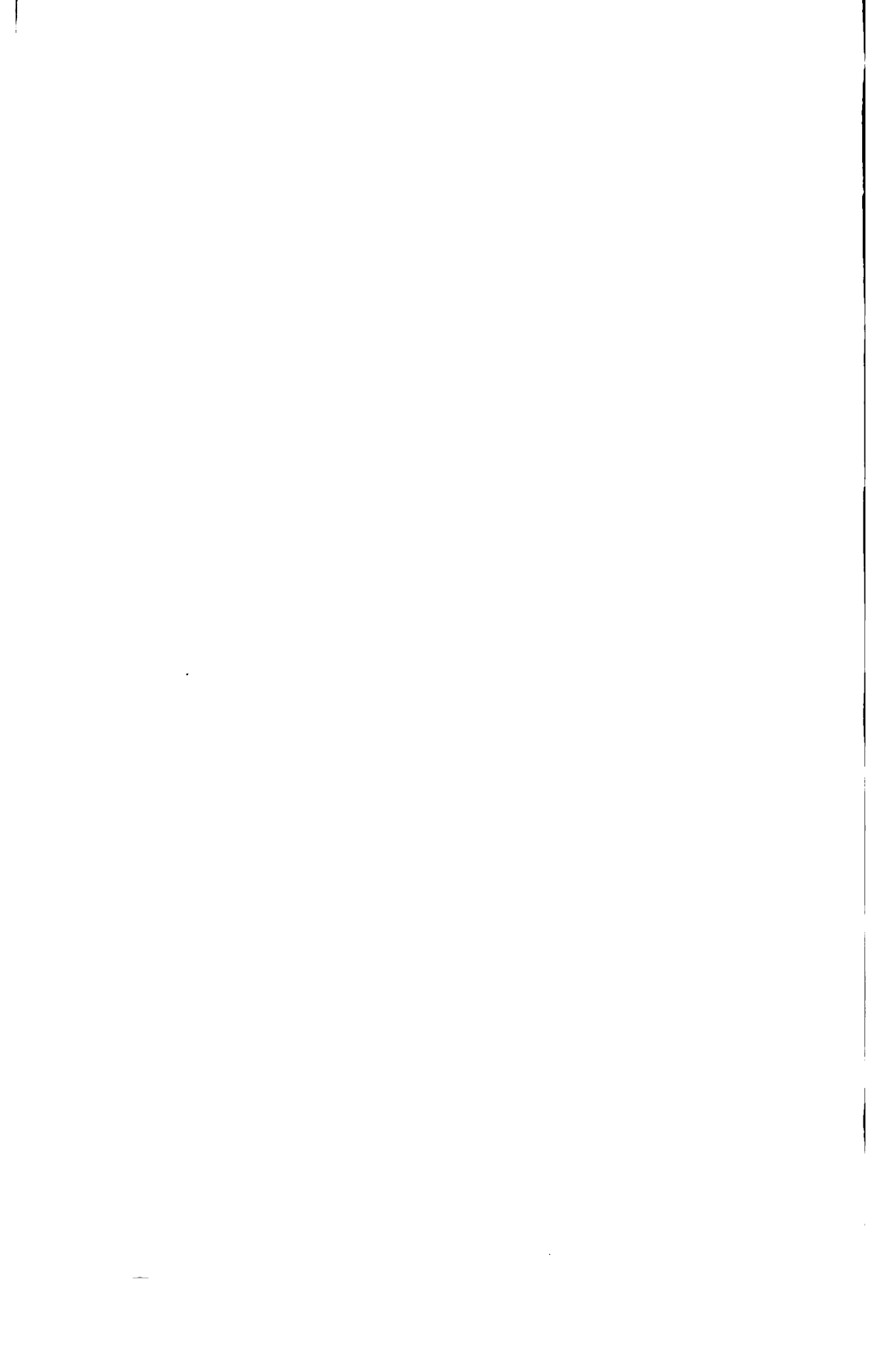


**PLATE 36.**

Woodworth.—Geological Expedition to Brazil and Chile.

PLATE 36.

Tumbres Peninsula; looking west from deck of steamer at anchorage.  
The flattish sky-line is that of a roughened peneplain. Page 126.



PHOTO BY J. B. WOODWORTH.

TUMBRES PENINSULA.

HELIO TYPE CO., BOSTON.



**PLATE 37.**

**WOODWORTH.—Geological Expedition to Brazil and Chile.**

**PLATE 37.**

**Modern Concepcion on the Rio Bio Bio, Chile. Page 125.**

Exp. to Brazil & Chile.

Plate 37.



PHOTO BY J. B. WOODWORTH.

MODERN CONCEPTION ON THE RIO RIO RIO.

HELIO TYPE OO. BOSTON.











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